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JANUARY, 1942

CONTENTS

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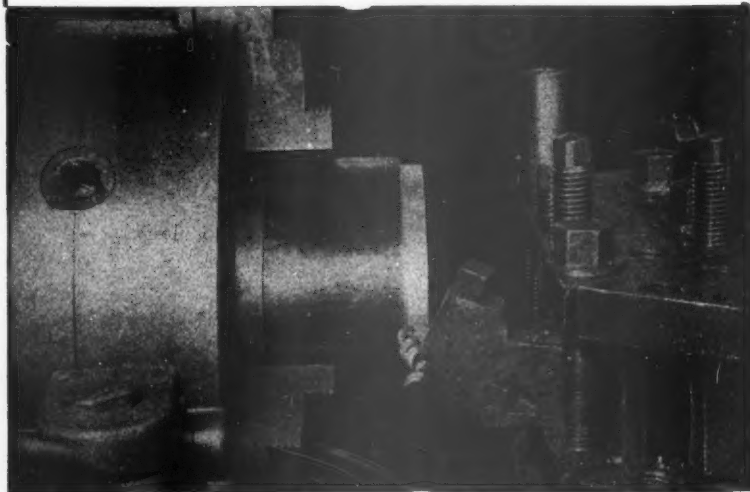

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* An excerpt from "Designing for Die Casting," published by New Jersey Zinc Company, New York.

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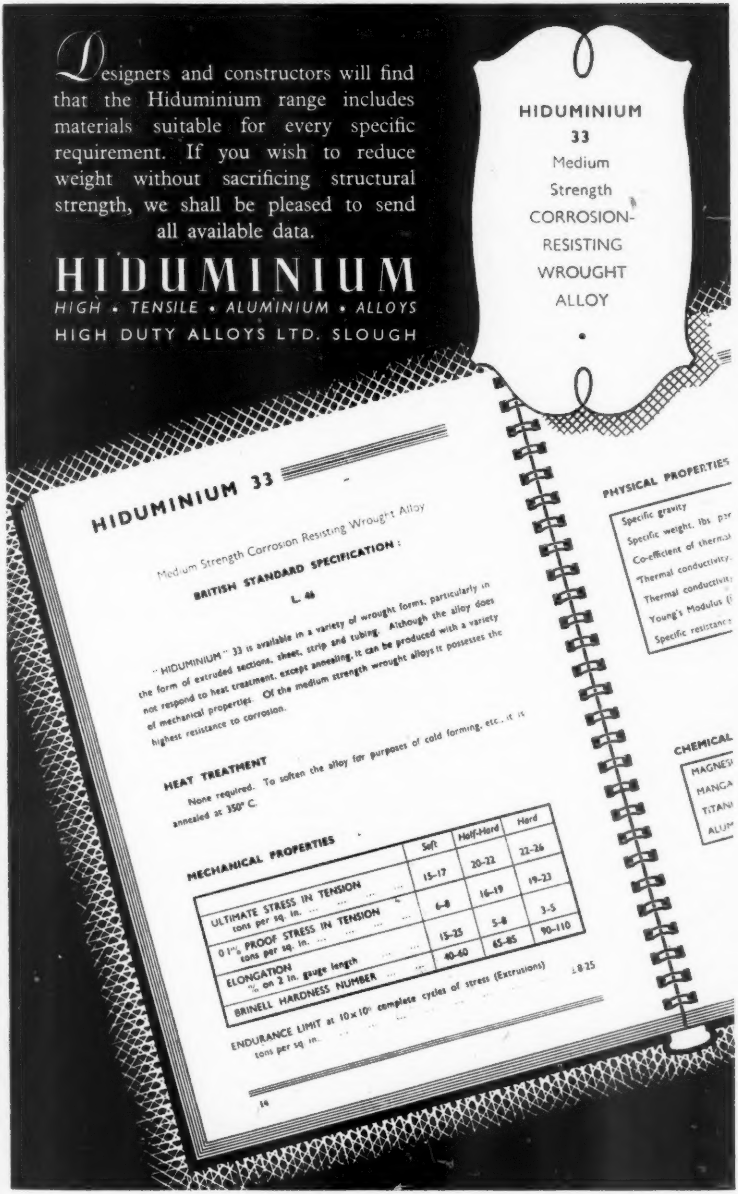
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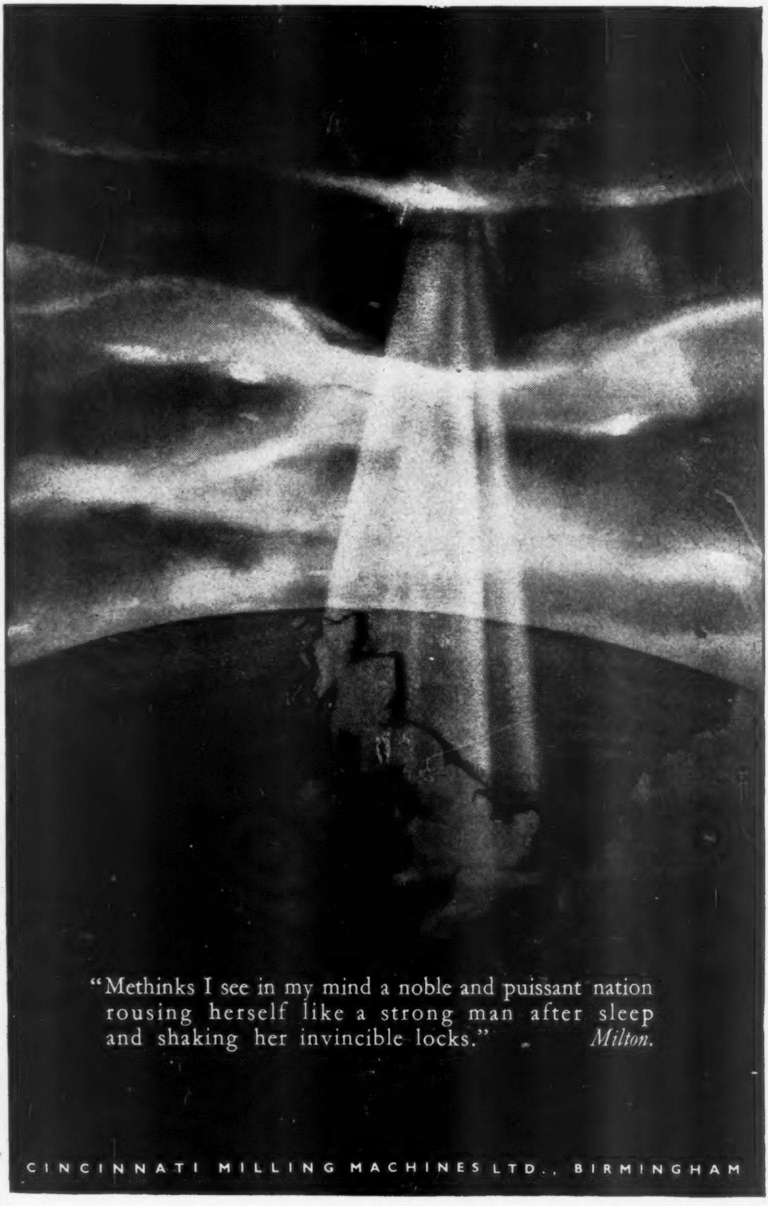
MECHANICAL PROPERTIES
Soft
Half-Hard
Hard
ULTIMATE STRESS IN TENSION tons per sq. in. 15-17 20-22 22-26
0·1% PROOF STRESS IN TENSION tons per sq. in. 6-8 16-19 19-23
ELONGATION % on 2 in. gauge length 15-25 5-8 3-5
BRINELL HARDNESS NUMBER 40-60 65-85 90-110
ENDURANCE LIMIT at 10×10⁶ complete cycles of stress (Extrusions) tons per sq. in. ±8·25
14
PHYSICAL PROPERTIES
Specific gravity
Specific weight, lbs per
Co-efficient of therm
Thermal conductivity
Thermal conductivit
Young's Modulus
Specific resistanc
CHEMICAL
MAGNES
MANGA
TITAN
ALUM


"Methinks I see in my mind a noble and puissant nation
rousing herself like a strong man after sleep
and shaking her invincible locks." Milton.
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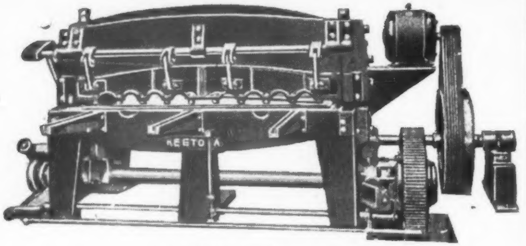

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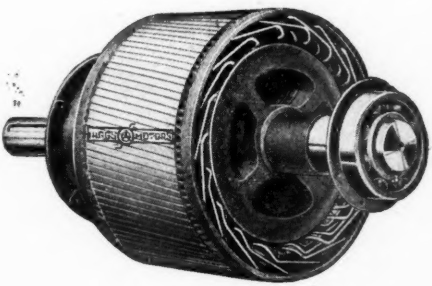

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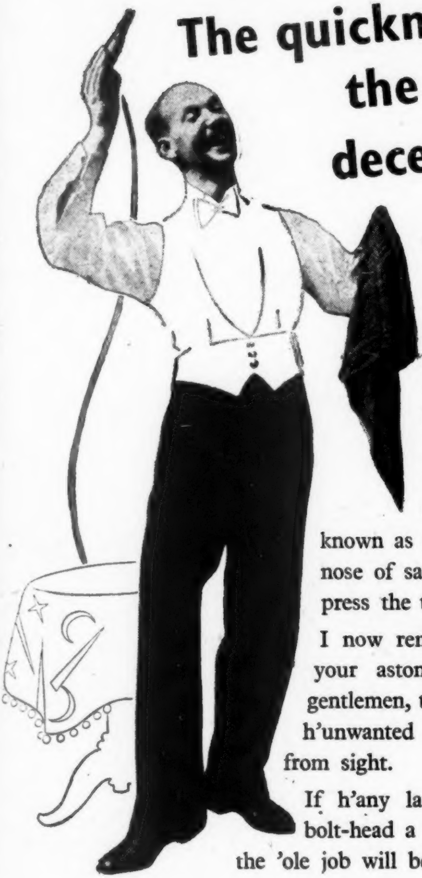

INSTITUTION NOTES

January, 1942

Fixtures

February 14—London Graduate Section. Headquarters. 2-30 p.m. Discussion on "Elements of Production Control," opened by Mr. L. E. Moore.

February 14—Manchester Section. College of Technology, 2-30 p.m. Informal Discussion on Production Problems.

The Report on Surface Finish

The Research Department of the Institution is publishing next month the "Report on Surface Finish," by Dr. Geo. Schlesinger, Director of the Department. The Report is one of major importance to all branches of the engineering industry in this country, and constitutes the outstanding achievement of the Research Department since its foundation three years ago this month. A Summary of the Report follows these "Notes."

The published price of the Report is 15s. (by post, 15s. 7d.), but it will be available to members of the Institution for 10s. 7d., post free. An Order Form is enclosed with this issue of *The Journal.*

Acceptance Test Charts for Machine Tools, Part II. Now Available

This has just been published jointly by the Institutions of Mechanical and Production Engineers, and may be obtained from Headquarters, price 5s. 6d. post free. Like Part I, it has been prepared by our Research Department. The charts cover (7) Capstan and Combination Turret Lathes, (8) Vertical Boring and Turning Mills, (9) Double Standard Vertical Boring and Turning Mills, (10) Planer Type Surface Grinders, (11) Surface Grinders with Vertically Adjustable Horizontal Grinding Wheel Spindles, (12) Cup Wheel Surface Grinder with Horizontal Wheel Axis, and (13) Cup Wheel Vertical Surface Grinders.

Meeting of the Council

The Council met in London on December 19th, 1941. Present: Mr. Kipping, chairman, the Deputy-President, Lord Sempill, Capt. C. W. Mustill, Dr. H. Schofield, M.B.E., Messrs. H. D. S. Burgess, W. F. Dormer, H. A. Drane, E. P. Edwards, G. H.

Hales, F. W. Halliwell, H. A. Hartley, E. J. H. Jones, J. T. Kenworthy, W. Puckey, J. D. Scaife, F. Williams. Also present: Messrs. A. E. Newby (Councillor-elect), R. Hazleton (General Secretary), and Miss Larbalestier (Office Manager).

Members in the King's New Year Honour's List

SIR CHARLES CRAVEN (Hon. Member), Controller-General, Ministry of Aircraft Production, has been made a baronet.

MR. H. H. HARLEY (Member) has received the honour of C.B.E.

Newly Elected Members

AS MEMBERS: H. A. Armstrong, G. S. Blackburn, A. Brown, B. H. Brown, M. Casey, H. E. Chipperfield, C. E. Dowrie, S. Dowse, W. C. Gravett, F. W. King, W. T. Kitching, F. W. Lee, F. K. Lord, A. F. Pool, W. J. P. Rodd, J. B. Robinson, M. F. Rowe, W. Scott, A. E. Stevens, R. V. Wood, L. Walker, A. P. Young.

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AS GRADUATES: J. Bradbury, G. P. Brown, E. W. Crew, H. Coulthurst (Jnr.), N. H. Dixon, A. V. W. Fiddler, R. I. Golding, C. R. Harrap, P. G. W. Hodge, J. H. Mills, R. C. K. Poulton, M. G. Page, J. A. Parker, C. C. Pickup, J. Quinn, J. W. Rhodes, L. Rutherford, F. Swain, S. A. Vandy, L. W. Wood.

As Students: G. G. Ayton, T. Barker, C. W. Blumfield, D. C. Boak, R. Black, W. E. T. Eglese, K. C. E. Hart, R. W. P. Johnson, A. P. Oppenheimer, E. J. Rice, W. E. Shackleton, J. S. White, R. Woodroffe, E. J. Yates.

As Affiliated Firms: Sir W. A. Armstrong Whitworth, Boulton Paul Aircraft, Compressor Accessories Ltd., Holman Bros. Ltd., Tyneside Safety Glass Co. Ltd., Aircraft Elements and Machine Tools Ltd., Broadway Engineering Co. Ltd., T. H. & J. Daniels Ltd., S. H. Muffett, Humber Ltd.

Transfers

From Associate Member to Ordinary Member: D. Braid, H. Haynes, P. Kellett.

From Intermediate Associate Member to Associate Member: A. H. Laycock, G. C. Miles, E. Scott.

From Graduate to Associate Member: J. A. Brockie, G. A. Turner.

From Graduate to Intermediate Associate Member: W. D. B. Haynes, T. Lever, H. Whitehead, D. P. Holt, F. J. Taylor, N. E. Langdale, R. R. Watkins.

From Student to Graduate: S. Dawson, P. C. T. Goodrum, H. W. Lawton, R. P. Walford.

Subscriptions Received for Research

Since the list in last month's "Notes," the following subscriptions for the work of the Research Department have been received:—

	£	s.	d.
W. Asquith, Ltd.	26	5	0
Glacier Metal Co. Ltd.	25	0	0
Cooksedge & Co. Ltd.	10	0	0
Hobbies Ltd.	5	5	0
	£66	10	0

Message from the President

This will be found in the January issue of *The Technical Bulletin.*

Progress of the Sydney (N.S.W.) Section

Reports from Sydney (N.S.W.) indicate that the Sydney Section of the Institution continues to make very satisfactory progress. At the Annual Meeting of the Section on October 14th, 1941, Mr. Jack Finley was elected Section President in succession to Mr. E. C. Parkinson. Messrs. Parkinson and S. D. McPhee were re-elected to the Committee. Membership at the date of the Annual Meeting was over 70.

Lecture meetings and works visits continue to be well supported. Amongst recent papers read and discussed was one by Mr. B. S. Round, Assistant Controller of the Fuse Section, Ministry of Munitions, on the subject of "The Manufacture of Fuse Parts." Eighty-five members and visitors were present, and Lieut.-Colonel Rowe, Controller of Gun Ammunition Production, Ministry of Munitions, and Mr. A. Maling, Area Controller of Gun Ammunition, were present. The Annual Meeting expressed its appreciation of the work done by the Hon. Secretary, Mr. James M. Steer. Amongst the activities of the Section the educational side has taken its place, and the Committee has been in co-operation with the Sydney Technical College in furthering there a new course in Production Engineering.

Appointment of Assistant Secretary (Technical)

The Institution has decided to appoint an Assistant Secretary (Technical). Particulars of the appointment are published in *Technical Bulletin*, No. 8.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "The Journal" should not be taken as an indication that they are necessarily available for export.

RESEARCH ON SURFACE FINISH

*Summary of the Report by the Research Department of the Institution

By Dr. Geo. Schlesinger, Director

SOON after the Research Department was established in January, 1939 it was decided that one of the earliest major tasks to be undertaken should be an investigation into the problem of surface finish. In July, 1939 the work on the subject was begun, and in March, 1940 a preliminary report was published in Vol. XIX, No. 3, of *The Journal.* Typical specimens to be investigated were sent by nineteen firms to the Research Department. The most important instruments both for measurement and comparison of surface finish were given or loaned by British and American firms. The research lasted from July, 1939 to March, 1941. The work was carried out with the assistance of the following members of the staff—Messrs. D. F. Galloway (Assistant Director, I. S. Morton, H. C. Holmes, and Mrs. M. H. Albery. The complete report is nowa vailable in book form, price 15s. 6d. nett. Members ordering copies for their own use will be charged 10s.

The following review is an extract of the results and will suffice to give our members an impression of the kind and amount of work which has been done.

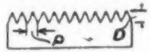
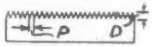
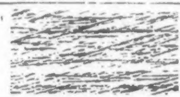
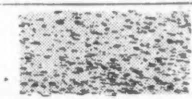
CHAPTER I.

Principal Factors Involved.

(1) Surface finish is important in all types of operative surfaces (Fig. 1). (2) Contrast between the existing accurate control of chemical or physical properties and dimensional tolerances on the one hand and the lack of clearly defined conditions of surface finish on the other. (3) Smoothness versus brightness—replacement of tests depending on sight or touch by more precise methods. (4) Important surface characteristics (*a*) waves (*b*) roughness (Fig. 2). (5) The scope of the research, introduction of exact measuring methods based on the inch.

* " SURFACE FINISH : *Report of the Research Department of the Institution of Production Engineers, November, 1941.*" Published by the Institution, 36, Portman Square, London, W.1. Price 15s. 7d. nett., (225 pages).

Vol. XXI, No. I, January, 1942.

Machining Operation	Diagram of Surface Shape	Feed: P = Pitch in.	Feed: D = Depth in.	Depth D mu. in.	Class of roughness
Finish Turning		.002 to .010	.000025 to .000400	25 to 400	5 to 9
Diamond Turning and Boring		.0001 to .002	.000003 to .000016	3 to 16	2 to 4
Commercial Grinding		.0005 to .002	.000016 to .000125	16 to 125	5 to 7
Fine Grinding		.0001 to .002	.000003 to .000016	3 to 16	2 to 4
Honing		Regular single scratches	.000002 to .000030	2 to 30	2 to 5
Lapping		Irregular fine criss-cross scratches	.0000008 to .000010	.8 to 10	0 to 4
Superfinish*		Fine random scratches	.0000005 to .000008	.5 to 8	0 to 3

Tolerances for standard holes class B inch: Dia. of hole	Max. tolerance
0.25	.0003
0.5	.0004
0.75	.0005
1.0	.0006
1.5	.0007
2.5	.0008
3.0	.0009
4.0	.001
5.0	.0011
10.0	.0016
20.0	.002

*not tested by Research Department.

Comparison of pitch and depth of feed scratches.

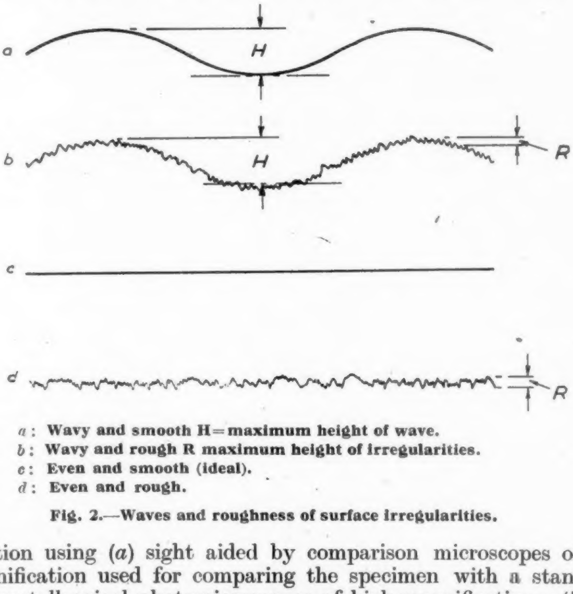
Fig. 1.—Characteristics of typical surface accuracy compared with standard dimensional tolerances.

Chapter II.

Aims of the Research and Results (c.f. the preliminary report of March, 1940).

The aims were: (1) To compare existing methods of observing surface finish. (2) To replace the present loose descriptive methods by a more definite system for measuring surface finish. (3) To suggest symbols for use on drawings. The results are—

(1) *Comparison of existing methods of observing surface finish.* The comparison of methods included: (i) Quantitative measurement of surface finish using (*a*) tracer instruments giving average readings and graphs; (*b*) an optical surface tester. (ii) Qualitative classification using (*a*) sight aided by comparison microscopes of low magnification used for comparing the specimen with a standard, and metallurgical photomicroscopes of high magnification; (*b*) the sense of touch, e.g. coin test (viz. scratching the surface with the edge of a coin and listening to the sound); (*c*) combination of touch and sight (smoothing the surface by a fine honing stone).



a: **Wavy and smooth H = maximum height of wave.**
b: **Wavy and rough R maximum height of irregularities.**
c: **Even and smooth (ideal).**
d: **Even and rough.**

Fig. 2.—Waves and roughness of surface irregularities.

(2) *Replacement of the present loose descriptive methods by a more definite system for measuring surface finish.* Approximately 450 surfaces of all kinds of different materials, fits, functions, and dimensions were measured. The findings were put together in a

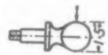
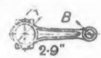
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							T.T.H. average meter	Profilometer	T.T.H. graph	Schmaltz	Material	Hollows	Form factors Material $F_1 = h_1$	Hollows $F_2 = h_2$	Remarks
Sur-face No.	Descrip-tion	Material	Function and fit	Machining operations	Sketch	Class No.	h ave mu.in.	h rms mu.in.	h max mu.in.	h max mu.in.	h_1 mu.in.	h_2 mu.in.	h max %	h max %	(G) means average taken from the graph
					LORRIES AND	BUSES									
102	Sleeve, position I.	Cast iron.	Easy slide fit.	Honed in position.	Do.	7	66	—	120	—	89	31	74	26	
103	Steering ball.	3% nickel case hardening steel.	Normal running fit.	Form ground.		4	13 (G)	—	40	—	26	14	65	35	
104	Crankshaft position A.	Nickel chrome steel stamping.	Running fit	Ground and lapped with emery cloth.		5	28	—	—	—	—	—	—	—	Too wavy.
105	Crankshaft position B.	Nickel chrome steel stamping.	Running fit	Ground and lapped with emery cloth	Do.	2	3.3	—	15	—	7.5	7.5	50	50	
106	Crankshaft position C.	Do.	Medium keying fit.	Do.	Do.	5	18	—	75	—	48	27	64	36	
107	Connecting rod, position A.	Ni-Cr. stamping lead bronze bearing.	Close running fit.	Fine bored.		5	20	—	65	—	35	30	55	45	
108	Do. position B.	Bronze bush.	Close running fit.	Do.	Do.	4	15	—	32	—	18	·14	56	44	

Table of Results. This Table which indicates present day surface finish practice has 50 pages, a sample of which is reproduced in Fig. 3. We are aware that improvements will be made, but we believe that the Table will be a useful guide for the immediate future.

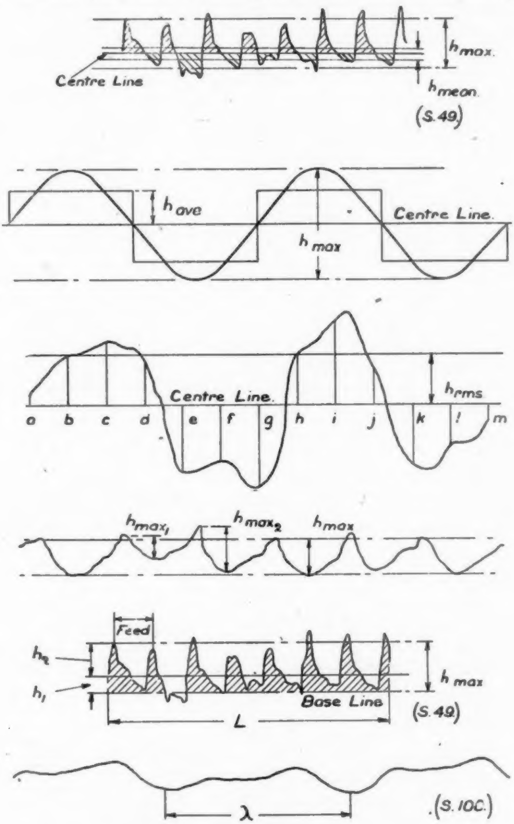


Fig. 4.—Alternative units of measurement: parameters.

(This is a case similar to the introduction of fits and limits of dimensions in 1902. Very many workshops did not tackle this difficult problem at all). The Table gives the results of careful measurement of surface finish as representing different practices in different

industries. With these results before us we considered the best method of defining the surfaces.

The height (or depth) of the undulations of the surface can be expressed numerically in various ways. For example, we can measure the total height h max (Fig. 4), also the average height of every point in the curve from some convenient base line. Such a base line might reasonably be drawn (*a*) along the crests, (*b*) along the roots, (*c*) as a centre line. The average from the selected base line can be computed in at least two practical ways: (i) as the arithmetic mean value (h ave), (ii) as the root mean square (rms) value (h rms).

To avoid an overwhelming number of columns we determined, from the root and crest base lines, only the arithmetic means, designating these h_1 and h_2 respectively. From the centre line we measured both the arithmetic and the rms values, designating these h ave and h rms. As the ratios of h_1 and h_2 to the overall height, h max, have some significance, $F_1 = \frac{h_1}{h \text{ max}}$ $F_2 = \frac{h_2}{h \text{ max}}$ (form factors), these were also calculated. After comparing all these numerical assessments, we concluded that the arithmetic average height h ave, measured outward from the centre line, would prove the most convenient unit for workshop use. It is easy to measure electrically, easy to determine from graphs, and is probably the easiest kind of average to understand.

The next most suitable parameter was the rms value, measured from the centre line. This is the unit ($h$rms) proposed by the Americans. Although equally easy to measure electrically, its determination from graphs is troublesome and it is not so easy to understand. It has great significance for the electrical engineer, but not, we concluded, for the production engineer. We were afraid the choice of the simpler h ave might lead to confusing numerical differences as compared with the existing American system, but we happily found that the inherent differences were generally small enough to be neglected.

Proposal for a British Standard.

Having decided in favour of the arithmetic mean (h ave) we drew up a table of progressively increasing classes of finish. This follows closely a corresponding American table based on h rms. Both tables are shown in Fig. 5. We propose to designate our classes by the numbers shown alongside. Top and bottom limits of roughness are then automatically implied by the class number. The results are arranged according to (*a*) industries and machining operations, (*b*) components and machining operations, (*c*) fits and functions.

The review of (*a*) "industries and finishing operations" is reproduced in Fig. 6. This figure is a summary of all finishing and

Proposed American standard (B.46)			
Step No.	h rms mu.in.		Symbols for drawing and workshop
1	¼		$\overset{32}{\vee}$
2	½		
3	1		
4	2	2 : 1	M = 1000 mu.in.
5	4		
6	8		$\underset{\vee}{16\text{M}} = \underset{\vee}{16000}$
7	16		
8	32		
9	63		Without indication of the machining operation.
10	250		
11	1000		
12	4000	4 : 1	
13	16000		
14	63000		

Proposal for a British standard		
Roughness Class No.	h ave = (h rms) mu.in.	Symbols for drawings and workshop
0	0-1	
1	1.1-2	Turning = *T*
2	2.1-4	Diamond turning = *DT*
3	4.1-8	Grinding = *G*
4	8.1-16	Honing = *H*
5	16.1-32	Lapping = *L*.
6	32.1-63	Polishing = *Po*
7	63.1-125	Boring = *B*
8	126-250	Diamond boring = *DB*
9	251-500	Reaming = *R*
10	501-1000	Milling = *M*
(11)	1001-2000	Planing = *P*
(12)	2001-4000	Scraping = *S*
		Broaching = *Br*
		Class 11 and 12 for rough classification only. Symbols on drawings:
		$\overline{\text{T}}\ \overset{4}{\vee}$ = Turning, class 4.
		$\overline{\text{L}}\ \overset{1}{\vee}$ = Lapping, class 1.
		$\overline{\text{M}}\ \overset{9}{\vee}$ = Milling, class 9.

Fig. 5.—Proposed American Standard and Proposal for a British Standard.

		FINISHING OPERATION					
Industries		Grinding	Turning	Diamond turning	Lapping	Boring	Milling
Automobiles.	Number of surfaces. (*a*)	32	8	4	8	1	8
	Aver. mu.in. (*b*)	18	85	26	6	66	77
	Max. ,, (*c*)	51	209	55	15	—	115
	Min. ,, (*d*)	3.2	12	15	1.5	—	12
'Buses and lorries.	Number of surfaces.	64	21	—	4	5	2
	Aver. mu.in.	18	85	—	2.7	79	81
	Max. ,,	51	215	—	3.3	181	129
	Min. ,,	3.7	13	—	2.3	15	34
Aeroplanes.	Number of surfaces.	18	8	6	7	1	1
	Aver. mu.in.	14	28.8	8.4	1.7	3.4	23
	Max. ,,	30	17	17	3.5	—	—
	Min. ,,	1.5	2.6	2.6	.98	—	—
Electrical	Number of surfaces.	14	3	—	1	—	1
	Aver. mu.in.	19	44	—	27	—	13
	Max. ,,	26	84	—	—	—	—
	Min. ,,	9.6	9.8	—	—	—	—
Machine tools.	Number of surfaces.	33	2	—	—	—	—
	Aver. mu.in.	15.5	47.5	—	—	—	—
	Max. ,,	52	62	—	—	—	—
	Min. ,,	2.2	33	—	—	—	—
Gauges (excluding slip gauges).	Number of surfaces.	9	—	—	21	—	—
	Aver. mu.in.	8	—	—	1.32	—	—
	Max. ,,	25	—	—	2.9	—	—
	Min. ,,	1.8	—	—	.5	—	—
Slip gauges.	Number of surfaces.	—	—	—	25	—	—
	Aver. mu.in.	—	—	—	.44	—	—
	Max. ,,	—	—	—	.5	—	—
	Min. ,,	—	—	—	.37	—	—

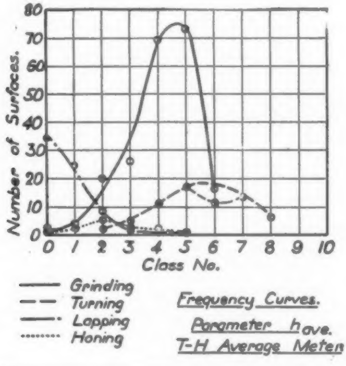
Fig. 6.—Review of Industries and Machining Operations.

fine finishing operations shown for selected industries and operations, giving (*a*) the number of surfaces checked, (*b*) the average finish in micro-inches, (*c*) the roughest surface in micro-inches, (*d*) the finest surface in micro-inches.

As an example, the table shows that the average roughness (*h* ave) of finish grinding operations is for—

(1) Automobiles	*h* ave = 18	micro-inch derived from	32 surfaces.
(2) 'Buses and lorries	*h* ave = 18	" "	64 "
(3) Aeroplanes	*h* ave = 14	" "	18 "
(4) Electrical machinery	*h* ave = 19	" "	14 "
(5) Machine tools	*h* ave = 16	" "	33 "

This shows a high standard. The numerical results shown in the table can be represented by "frequency" graphs. Fig. 7 illustrates the distribution of the most important finishing operations



Operation	Class Number 0	1	2	3	4	5	6	7	8	9	10	Total
Grinding	3	4	20	26	69	73	16	—	—	—	—	211
Turning	—	—	2	5	11	17	12	14	6	—	—	67
Lapping	34	22	9	2	1	1	—	—	—	—	—	69
Honing	1	2	5	2	2	1	—	—	—	—	—	13
											Total	360

Fig. 7.—Frequency graph of *h* ave of the four finishing operations.

measured as *h* ave. The report now presented covers the most up-to-date knowledge on the subject and sets out the results obtained by the Research Department.

Apart from measurement of the height of the irregularities,

qualitative classification based on their appearance has some advantages. We used a metallurgical microscope, generally with magnifications from 100 to 1,000, to show visually or photographically the effects of different machining methods on surface finish.

We also used a comparison type of microscope of low magnification (from 30 to 40) which is held in the hand and is easily applied to different specimens, and through which an image of the specimen is seen alongside that of a master, the two being equally magnified and illuminated.

(3) *Selected symbols for use on drawings.* The drawings must show (*a*) method of machining, (*b*) the required finish, preferable expressed by the class number of its average height. The proposed symbol is shown in the following example $\overline{\text{G}}\overset{3}{\vee}$ This indicates a ground surface, class (3).

CHAPTER III.

The Negligible Influence of the Scratch Effect of Modern Tracer Instruments.

Because the most important results both in Great Britain and in the United States were based on the use of tracer instruments, in which a stylus of known but very minute radius is traversed over the specimen, it was necessary to discover whether the stylus scratched the surface and, if so, whether the scratch mattered. We found that with a tip radius of .0001 in. and a pressure of .2 gms. only the softest non-ferrous metals were appreciably scratched. The scratch, however, appeared to be of uniform depth, and we concluded that it would generally have no serious effect on the results.

CHAPTER IV.

Relation of Dimensional Roughness to Dimensional Tolerances.

Measuring instruments of all kinds have anvils that engage an area of the surface that is appreciable compared with the average pitch of the irregularities, and this is true even of spherical anvils. Thus. all dimensional measurements are taken over the crests of the undulations. For most uses of the surface, however, it is the size to the centre line, or even the roots of the undulations, that will ultimately count. If it should happen that the depth of the undulations is comparable with a required dimensional tolerance, then clearly the roughness should be taken into account in setting the tolerance. It was thought desirable to investigate this matter

in detail. It was found that the relation between the roughness of the surface and the fine tolerances that are now becoming quite usual is very definitely of practical importance. Because the future aim of interchangeable manufacturing is non-selective assembly, the slip-gauge system is dealt with, as it forms a particularly good example of the reciprocal influence of surface roughness on dimensional accuracy.

CHAPTER V.

Instruments for Measurement of Surface Finish.

The instruments which have been used by the Research Department in the investigations are broadly of two types.

(*a*) *For quantitative measurement.* (1) Tracer instruments, employing a stylus which is traversed over the surface. Some of these give results in the form of a graph, others give a single reading, which represents more or less the average roughness of the surface. *Examples*—profilometer by Abbott (U.S.A.), surfacemeter by Taylor Taylor & Hobson, Ltd. (British). (2) Optical instruments through which may be viewed the contour of the surface. *Example*—surface tester (Schmaltz) by Zeiss (German).

(*b*) *For qualitative classification.* (1) Comparison microscopes, by means of which samples can be compared optically in appearance with masters which must have been produced by the same process as the samples. *Examples*—comparison microscope by Klemm (U.S.A.), comparison microscope by Taylor, Taylor & Hobson, Ltd. (British). (2) Metallurgical microscopes. *Examples*—Vicker's microscope by Cooke, Troughton & Simms, Ltd. (British), " Metaphote " by Busch (German). The instruments are compared and reported upon in terms of (*a*) principles of design, (*b*) unit of measurement or basis of comparison, (*c*) range, (*d*) accuracy and scope, (*e*) calibration. Other instruments that were taken into account though not actually used in the Research Department were: (1) optical smoothness meter by J. Guild, N.P.L., (2) recording instrument for surface finish by Dr. G. A. Tomlinson, N.P.L.

CHAPTER VI.

Development in U.S.A.

The investigation would be incomplete if it were to neglect the knowledge existing in the U.S.A., where for ten years the study of Surface Finish has been considered to be a most important problem. We finish our report, therefore, with a short survey of American achievements, giving (1) History. (2) Proposed American standard. (3) Development of workshop surface analysis. (4) Improvement of production technique (superfinish).

(1) The American Standards Association worked on the recommendation of the American Society of Mechanical Engineers from 1932 to 1940. The Sectional Committee represented twenty-eight interested organisations which organised sub-committees whose business it was to make a detailed study of the several branches of this broad subject of surface qualities. The revised draft of the proposed Standard (B.46) was published in March, 1940 for a trial period of not more than two years.

(2) The proposed American Standard is published in Fig. 5 (left). The American table is based on *h* rms (root mean square average), the British proposal on *h* ave (arthmetic mean). The two American instruments in actual use are the Abbott profilometer, which gives in a single number the *h* rms values, and the Brush surface analyser, which only makes pen records. Abbott did great and outstanding work in the field of refined surface measurement in modifying the old tracer instruments, decreasing at the same time the radius of the stylus point to 0.0005 in. and the pressure behind the stylus to 0.1 gr., thus making negligible the unavoidable scratch influence.

(3) Abbott's instrument facilitated the workshop surface analysis which is necessary for introducing strict rules for the fourth essential of specimen characteristics, i.e. surface finish, for surface finish is essential for the correct functioning of mating components.

(4) The improvement of production technique consisted in developing a new kind of surface refinement called superfinish, developed by the Chrysler Corporation. This is, in effect, similar to fine lapping, but the means of making it and the speed of operation differ considerably from mechanical lapping operations. Superfinished surfaces range in classes 0 and 1 of the British proposal.

Acknowledgments.

The Research Department is indebted to the following firms for sending components, and for their interest and helpful suggestions :

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Rolls-Royce, Ltd., Derby.
Leyland Motors, Ltd., Leyland.
The Associated Equipment Co., Southall.
Alfred Herbert, Ltd., Coventry.
John Lund, Ltd., Keighley.

Coventry Gauge and Tool Co., Coventry.
Metropolitan-Vickers Electrical Co., Manchester.
L.M.S. Railway Co., Derby.
Taylor, Taylor & Hobson, Ltd., Leicester.
David Brown & Sons, Ltd., Huddersfield.
The Hoffmann Manufacturing Co., Chelmsford.
Newall Engineering Co., Peterborough.
The Pitter Gauge and Precision Tool Co., Woolwich.
Optical Measuring Tools, Ltd., Slough.

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Alfred Herbert, Ltd., Coventry—Zeiss-Schmaltz surfacemeter.
Gaston E. Marbaix, London—Abbott's profilometer.
Cooke, Troughton & Simms, Ltd., York—Vickers' microscope.
Charles Churchill & Co., Birmingham—Busch metaphote.

SAMPLING INSPECTION AND QUALITY CONTROL

Lecture presented to the Institution (London Section) by
Bernard P. Dudding, M.B.E., Ph.D., F.Inst.P., A.R.C.S.
(a Member of the Research Staff of the General Electric Company).

Introduction

I SHOULD like to preface my remarks by pointing out that I am not a statistician. For many years I have been associated particularly with the transfer of new developments from the laboratory to the industrial stage. In the early years of this work I realised that difficulties were met in the works other than those which had been solved in the research laboratories. The use of statistical methods has proved of considerable assistance in locating the sources of such difficulties. Because of this experience I hope this lecture will prove of practical utility to production engineers.

Further, I wish to emphasize two principles, although I shall tend to ignore the second this afternoon. Statistical methods cannot solve problems demanding a knowledge of engineering, chemistry, or physics, although under complex working conditions the use of the methods will help to locate where a problem lies. It is also necessary to combine sound technical knowledge of an industry with the use of statistical tools.* Unfortunately, I shall be ignoring this latter principle in some measure, because I have been asked to talk on a subject in a field of engineering in which I have had little personal experience since the last war. I hope, therefore, that you will not be too censorious if you find I " put my foot in it " once or twice.

The characteristic feature of quantity production in modern industry is repetition work ; that is, the objective is the reproduction of articles having close similarity. Nevertheless, we all know that it is quite impossible to achieve absolute similarity, whether similarity is judged by dimension, as in the diameter of a bolt or the pitch of a screw, or by tensile strength, as with cloth, wire, cement, bricks, and so on, or by electrical resistance, as in the case of parts of telephone equipment, &c. In all cases the recorded measurements will not be found to be identical, and the differences not due to differences in measurement, but actually found to exist in the articles themselves.

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*See section 5, *Statistics and Engineering Practice*, Dudding and Jennett. Jour. I.E.E.. 1940. Vol. 87, No. 523, p. 12.

December 12th, 1941.

Once it is conceded that variability is bound to be encountered in a manufactured product, some action must be taken to keep the degree of variability under observation. Common methods in industry are the "GO" and "NOT GO" gauge for dimensions; upper and lower limits for some continuously variable quantity, such as mechanical strength or electrical resistance; and upper and lower limits for composition, as in the case of alloys, chemical products, and many other processed materials. When such limits are used they are sometimes placed on the average value of test results on selected samples, sometimes on individual results based on bulk inspection, and sometimes on the individual results for a sample. All these precautions against too great variability are most commonly used for determining the test clauses in specifications governing the sale of goods by producer to consumer, but they will often be found operating within one organisation where the materials or components made in one section of the factory become the raw materials of another.

These precautions or controls are introduced because experience shows that in all manufacture wastage of both labour and material arise from the use of materials differing too widely from some desired objective. *By the effective use of the data obtained during manufacture, however, the need for checking for conformity to specification could be very substantially reduced.*

Utility of Statistical Methods

All the efforts referred to above to control variability, or to impose limits on the amount that will be tolerated, are indirect. Statistical methods based on the mathematical theory of probability concentrate attention directly on the variability. They provide "yardsticks" by which variability can itself be quantitatively measured, and also rules to guide judgment as to when action should be taken as a result of finding differences between test results. Where inspection of every individual item—what is known as 100 per cent inspection—is impracticable and/or uneconomic, then statistical methods of studying the test data are essential for making a right and balanced judgment, because in these cases the properties of the bulk supply are being inferred from results of tests on selected samples. In cases where 100 per cent inspection is done, the use of statistical methods may lead to a reduction in the amount of testing by showing that sufficiently accurate information can be obtained from samples. In all cases, the methods will assist in tracing the origin of variability, the necessary first step in any rational effort to reduce it and, when action has been taken, will provide a basis for determining whether or not an improvement has been made.

Stated as briefly as possible, the purpose of statistical methods in inspection are :—

(1) To indicate how to keep the quality or dimensions of a product, whether the final product, or a constituent part of the final product, under continuous check or control during the processing, so as to give warning—and I particularly wish to emphasize that the primary object is *to give warning* of : (*a*) any new source of error, (*b*) any increase in a known source of error, (*c*) the effect of any change deliberately introduced into the manufacturing procedure generally, of course, to improve quality and/or to reduce cost by reducing variability.

(2) To determine whether, on a basis of cost and convenience, the quality shall be appraised by means of the average test value or the range in the test values, or the proportion of the test values that fall below some specified limit, or by any other statistical parameter that is chosen as suited to the conditions.

(3) To enable a correct sampling procedure to be established ; that is, to determine the size of the sample in relation to the reliability which it is desired to place in the test results.

(4) To assist in tracing the origins of variation, with a view to improving the product and/or reducing waste.

(5) To help in adjudicating between rival proposals for reducing variation when a contributing source has been definitely ascertained.

(6) To improve conditions governing the sale of products to consumers. (In any industry whose methods of inspection and recording are governed by an appreciation of statistical methods, the common form of specification involving testing often becomes redundant, because the manufacturer's records will demonstrate clearly the level of quality he has attained, and whether the quality is effectively controlled at that level.)

The plan adopted in this lecture for introducing statistical methods to those responsible for the quality of a quantity-produced product is based on very considerable practical experience, and is aimed at utilising test data which will usually be found recorded at many stages in modern manufacturing organisations. It does not seek to introduce something which is wholly new ; there is hardly a manufacturing organisation which has not " stacks of data " which have never been properly used. Subsequent adjustment of the methods of sampling inspection and recording follows as a natural consequence of practising the methods.

The economic value of statistical methods lies in their ability to indicate real, as distinct from apparent trends in quality, thus enabling preventive action to be taken to maintain quality, whereas the more usual inspection methods yield information only when

the sole cure left open is to scrap. I want to emphasize again this question of taking preventive action. I know that many production engineers will have had first hand experience of some such sequence of events as the following :—

Some particularly adverse test results suggest that a fault has developed in the factory, and those responsible take drastic action with both staff and procedure. The trouble disappears, either without a clue being found as to the cause, or alternatively, cure is attributed to one of several changes made, but the same trouble appears again a month later. In many cases there has been no new source of trouble, but waste has been incurred because the statistical implications of the factory checking procedures have not been realised.

In general terms, which will be appreciated by quantity production engineers, the use of statistical methods will change the inspector's role from that of an unsympathetic detective to that of a helpful constable. The inspecting engineer will come to be judged, not by the amount of material he scraps, but by the amount of help he gives to the production engineer in maintaining rejections at a low value.

Here I should like to emphasize that the neglect of statistics by engineers is criminal. Engineers refer to catalogues when requiring voltmeters, micrometers, &c., and would consider themselves ill-informed if they did not know the contents of every reliable manufacturer's catalogue. Here, in this book of tables† are the fruits of hundreds of hours of labour of statisticians and mathematicians. Engineers have only to learn how to use them, but very few have ever opened the covers.

Control of Manufacturing Procedures

The methods now to be described in detail are intended to indicate when a change is taking place in the quality of articles produced in quantity. Stated differently, they aim at indicating when a manufacturing system is stable or otherwise. Therefore, it is desirable at the outset to obtain a clear conception of what is meant by describing a manufacturing system as stable or under control. Figs. 1 to 7 are examples of what are commonly known as "frequency distributions." The total range in the test values is shown to scale horizontally and this is divided into 10 to 20 parts, the number of test results which falls within each of these subdivisions is shown to scale vertically. The diagrams indicate therefore the frequency with which articles will be found in a bulk product having certain values on a quality scale. The illustrations

†*Tables for Statisticians and Biometricians*, Part 1. Biometrika Office, University College, London.

have been purposely chosen to show how wide a range of products exhibit similar characteristics in respect of spread and quality.

Fig. 1 gives data for the anode current of a type of receiving valve;

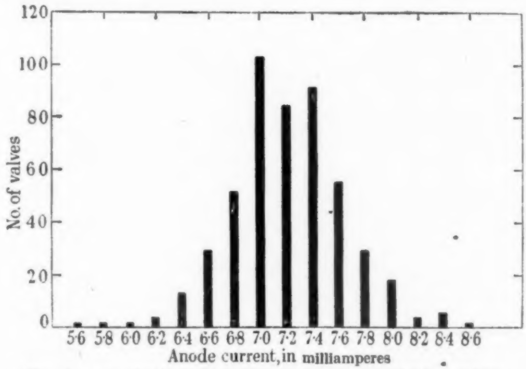


Fig. 1—An electrical characteristic of receiving valves.

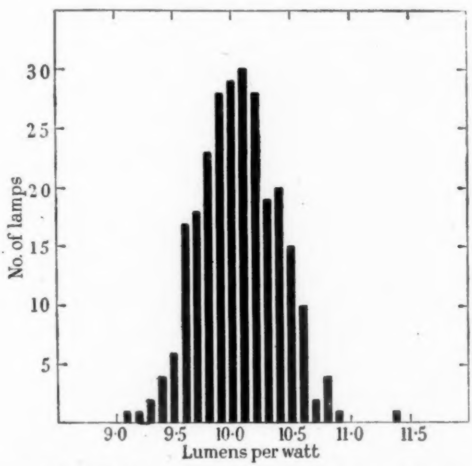


Fig. 2—Initial efficiency of 40-watt electric incandescent lamps.

Fig. 2 gives data for the initial efficiency of an incandescent lamp measured at the voltage marked on the lamp;

Fig. 3 gives data for the breaking strain of glass tubing which is regularly sampled as it comes off an automatic machine in order to make sure that no change is taking place which adversely affects the strength of the glass.

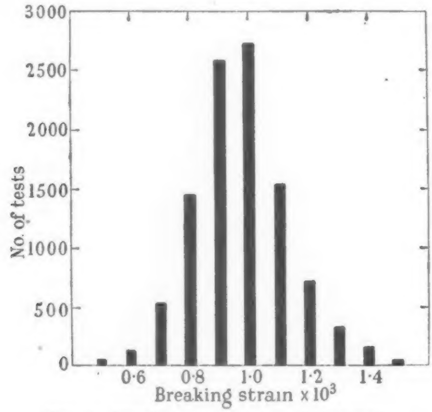


Fig. 3—Breaking strain of glass tubing.

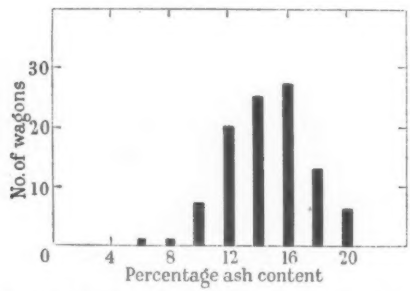


Fig. 4—Percentage ash content in wagons of coal.

Fig. 4 gives the ash content obtained when sampling wagons of coal in a delivery.

Fig. 5 gives the voltage difference from nominal value at different points on a supply system.

Fig. 6 gives data for the load required to break cotton fabric. (This is an interesting case because the curve is asymmetrical; later on I shall refer to a method for handling cases of this kind.)

Fig. 7 gives data for the diameter of glass tubing.

All these examples have something in common. The results tend to be clustered round some objective set by the manufacturer, and they tail away at each side : the further away from the objective

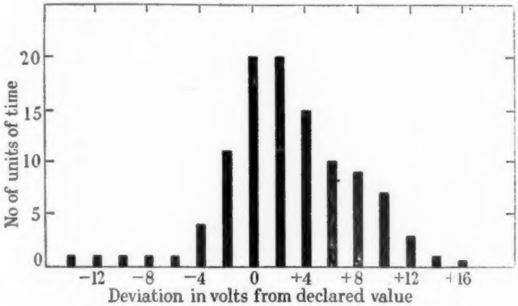


Fig. 5—Voltage distribution on a network.

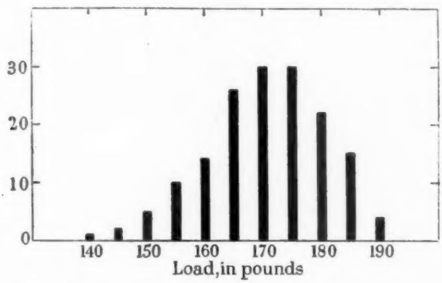


Fig. 6—Breaking load of strips of cotton fabric.

the fewer the results. Now if a product be examined at frequent intervals, and the results yield a diagram of this type every time so that its position along the quality scale and the spread are closely the same, the manufacturing system is stable or controlled in spite of the fact that obviously variation exists. In such a case the variation arises from a large number of uncontrolled factors, factors which it is impossible or inconvenient to control. Usually it will be found, on careful consideration, that lack of control is due to lack of knowledge and/or some limitation imposed by convenience or cost. In very many cases it is fundamentally due to

lack of knowledge, because when control " is not convenient " or " it costs too much " it is really because the need exists for new knowledge or a new tool to enable control to be exercised.

The line of argument usually followed when applying statistical methods is :—

(1) The assumption is made that the manufacturing system is stable or under control; that is the product, considered in bulk, is not changing in respect to the magnitude of and the spread in the quality characteristic on which interest is centred for technical reasons.

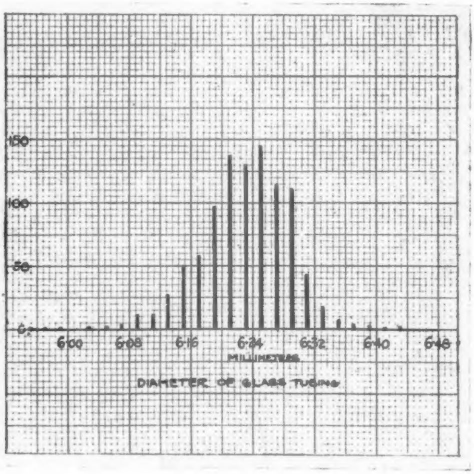


Fig. 7.

(2) From previous knowledge, or by examination of a reasonably large representative bulk of the product, a commercially attainable standard of quality is adopted.

(3) Statistical theory is used to prescribe some limits within which the results for a sample contained in a few articles should fall on some " convenient " proportion of occasions, if the sampling be repeated many times and the conditions of manufacture are as assumed in (1) ; that is, are stable. (Statistical theory also gives guidance in determining the size of the sample and the " convenient " proportion which is chosen when fixing limits, in relation to other matters, such as the cost of testing and the magnitude of the change in quality which can be permitted on grounds of cost and/or safety.)

(4) Assumption (1) is confirmed if the results fall within the limits which are prescribed, and further testing is unnecessary.

(5) Assumption (1) is not confirmed if results occur outside the adopted limits (3) more often than the proportion expected, or if too many results are found near these limits. Such events give warning that a change may be taking place in the manufacturing procedure. Further testing and possibly investigation are then necessary.

A Simple Example—Control of Proportion "Defective"

Having stated as briefly as I can, and I hope reasonably clearly, (*a*) the reason for utilising statistical methods and what they are designed to achieve, and (*b*) the line of thought adopted, I will illustrate the procedure by means of a simple example. Consider an article tested for a dimension by means of "GO" and "NOT GO" gauges. This is a class of work of which I have not much experience. However, if the argument is not wholly sound this should prove to be a good example for engineers present to see how far they are able to utilise the methods to be described in similar cases. I am quite sure that the methods can be used. The introduction of a sampling system assumes that the inconvenience and cost caused on final assembly by a small proportion of the product being outside the limit gauges is not larger than those which arise from wear of gauges, lapses on the part of the inspection staff and so on, when 100 per cent inspection is done. (It is common knowledge that in spite of 100 per cent inspection, complete freedom from trouble on final assembly is not obtained.) In this example it is also assumed that information already exists which indicates that about 1 per cent of the product fails to pass the limit gauges when production is progressing satisfactorily in the normal way. If groups of 100 articles are selected at random from a large bulk known to contain 1 per cent "defective" it is obvious that on the average one "defective" article will be found in each sample. However, it will be found in practice that many of the samples will contain no "defectives" whatever, whilst occasionally three, four, and even as many as six "defectives" will be found in a sample. This change in the number of "defectives" in a sample is often experienced in a factory, and it is usually thought to indicate a real change in the proportion of "defectives" in the bulk. Engineers in charge often assume that faulty and careless operation is the cause, and the consequent language and behaviour are not always conducive to smooth and harmonious working. It is a pity that such unnecessary trouble should arise simply from a lack of appreciation of a fundamental cause other than a change in quality.

My colleagues and I have tried to devise an experiment to demonstrate this variation in samples taken from a bulk having a

small proportion of "defectives." We have in a "hopper" several gross of small balls 1 per cent of them having been "blued" to serve as "defectives." By rotating a wheel five times a sample of 100 will be selected and the number of blue ones noted and recorded on a chart, as though the process was one of ordinary production. I will ask some independent person to act as observer. (The secretary of the Institution did so.) We shall return the sample to the "hopper," taking care to thoroughly mix the bulk so that each sample is a random selection from the same bulk.

(The experiment was then made seven times, the number of "defectives" recorded being respectively 0, 1, 1, 2, 1, 1, and 1.)

We should like to continue the sampling thirty or more times,

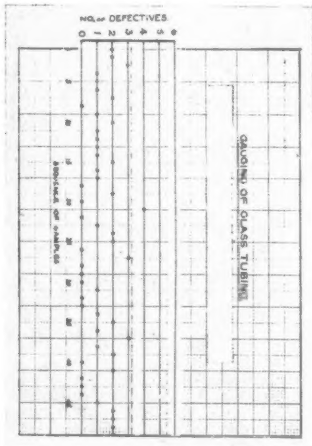


Fig. 9.

and will do so at the end of the meeting if anyone is interested, because higher numbers of "defectives" will sometimes appear.

Let us examine an example derived from production experience. In this case we are dealing with the data for glass tubing which was shown as a frequency distribution in Fig. 7. The tubing is gauged to limits 6·0 and 6·3 mm., and the average number of "defectives" expected in each sample is 1. The results for 49 samples taken in succession are plotted in Fig. 9. Note how the number of "defectives" change and in particular, after sample 17, how successive samples contained 2, 0, 4, 0 "defectives" respectively.

Before discussing these results in greater detail consider the theoretical data plotted in Fig. 8.‡ Along the horizontal scale is plotted the average number of " defectives " expected in the sample. For example, if samples of 50 are selected from a product containing 2 per cent " defectives," one " defective " would be expected on the average in each sample. On the vertical scale is plotted the probability that some other number of " defectives " will be found in the samples.

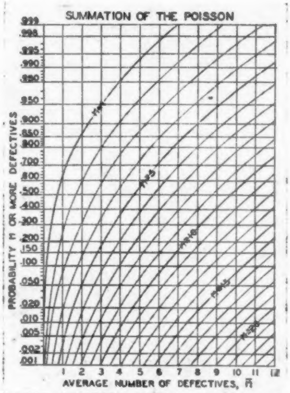


Fig. 8.

Thus, considering the same example where one " defective " is expected in each sample, Fig. 8 shows that one or more " defectives " will occur in about 64 out of 100 such samples, that is to say, there will be no " defectives " in about 36 samples. Similarly, two or more will occur about once in four ; three or more about once in 13 ; and as many as six or more will occur once in 2,000 samples.

The data given in a convenient form in Fig. 8 and Table 1 indicates what is likely to happen in a simple experiment of the kind we have just made, or as we shall see when testing samples selected from a stable product. Now return to the data plotted in Fig. 9, and compare them with the theoretical data. We have already noted that three or more " defectives " should be found in about 1 in 13 samples. In Fig. 9 it will be seen that on four occasions in 49 samples more than three " defectives " were found : Table 1

‡See also ref. p. 16, and Simon, *Engineers' Manual of Statistical Methods*, 1941, John Wiley & Sons.

TABLE 1.

"Defectives" in sample of 100 articles.	Proportion "defective" in bulk product. 1 per cent.	2 per cent.	3 per cent.
	Approximate proportion of occurrences in repeated sampling.		
0	7 in 20	3 in 20	1 in 20
1 or more	13 ,, 20	17 ,, 20	19 ,, 20
2 ,,	5 ,, 20	12 ,, 20	16 ,, 20
3 ,,	1 ,, 13	1 ,, 3	2 ,, 3
4 ,,	1 ,, 50	1 ,, 7	1 ,, 3
5 ,,	1 ,, 400	1 ,, 20	1 ,, 5
6 ,,	1 ,, 2000	1 ,, 60	1 ,, 12

shows that four or more should be found once in 50 samples, actually four were found once in 49 samples. No " defectives " were found in 14 samples of tubing, whilst on theoretical grounds we should have expected to find no " defectives " on 17 or 18 occasions. There is therefore, good agreement between the practical and theoretical data, and the manufacture can be considered as stable or under control. Under this set of conditions the sequence of events after sample 17 has a peculiar interest because it is very unlikely, in the absence of this statistical background that the occurrence of four " defectives " in a sample would not have led to a considerable disturbance in the factory.

I now wish to show how sensitive this method is when used to detect a change in the proportion of defective product by assuming that this has increased to 2 per cent ; that is, in a sample of 100 two " defectives " would be expected on the average. Referring to Fig. 8 or Table 1, it will be seen that three or more " defectives " should now occur once in three samples, instead of once in 13 samples when selecting from a product containing 1 per cent " defectives." Hence, too frequent occurrence of three " defectives " in a sample introduces an *element of doubt*, and serves as a *warning* that a change in the production system may be occurring. When sampling from a bulk having 2 per cent " defective " four or more will occur about once in seven samples, instead of once in 50 samples from a 1 per cent " defective " product.

It should be noted that the detection of a change in the proportion " defective " is associated with a change in the probability of some definite number of " defectives " being found in the sample. If a gradual change is taking place in the product then the sooner the probability of a definite number of " defectives " rises to an agreed value, the more sensitive is the procedure said to be.

Let us proceed to systematise the method of studying charts of " defectives" similar to Fig. 9. For this purpose it is convenient to arrange the data given in Fig. 8 in a slightly different form. In Fig. 8 the data are arranged so that the probability of some specific number of " defectives " occurring in the sample can be readily determined, but for the purpose in mind it is more convenient to be able to find, for a definite probability and proportion of " defective " in the bulk, how many " defectives " will be found in the sample. The data are so arranged in Fig. 10 where, as in Fig. 8, the number of " defectives " expected on the average in the sample

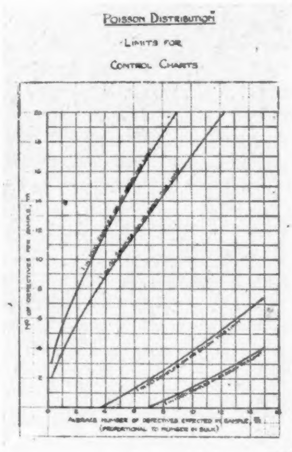


Fig. 10.

is plotted on the horizontal scale, but curves are drawn through points corresponding to the number of " defectives " which will be found on the average in the sample once in 40 and once in 500 samples respectively if sampling be repeated. These two probabilities have been chosen because long experience in the work with which I have been associated has shown that they are two of the most useful. For example, referring to Fig. 10, if the bulk contains 3 per cent " defectives," three " defectives " are expected in a sample of 100 articles, it will be seen that seven or more " defectives " will be found once in 40 samples and 10 or more once in 1,000 samples.

Using the limits determined by the probabilities a chart like Fig. 9 can be subdivided into three zones as indicated by the dotted lines. Provided that the test results, when plotted, are distributed in the lowest zone it can be assumed that production is proceeding normally; but if too many points are obtained near the lower dotted line or just above it they provide a *warning* that the quality of the product may be changing. Should results occur in the neighbourhood or above the upper line it is quite likely that a change in the product has taken place.

When results occur near the 1 in 40 limit it is usual to take additional samples to confirm or disprove the suspicion that the manufacturing procedure is not stable before taking action in the factory, whereas, if results occur near the 1 in 1,000 limit investigation in the factory is immediately desirable. Charts similar to Fig. 9 are often seen in factories with the test results plotted, but rarely are the limit lines indicated and consequently, as suggested earlier, when a "4" is followed by a "0," or particularly when a "0" is followed by a "4" the personnel of the factory get worried. However, if the guiding principles here indicated are followed, judgment will be made on sounder grounds than if made merely on observation of changes in the number of "defectives" found in samples.

Repeat Sampling. Compounding Data.

I should like here to comment on the method of handling when additional samples are taken, because so often, even in specifications, such data are wrongly handled. When a second sample is selected from the same bulk the two results should be compounded and treated as derived from a single sample, the compounded result being referred to new limits, and not treated as two separate samples referred to the old limits. In the case above considered a second selection would bring the sample size up to 200 and, on the average, two "defectives" would be expected. Referring to Fig. 8, it will be noted that in such a sample six or more "defectives" are likely to be found once in 50 samples. If this occurred—although the action taken usually depends on the nature of the work—I would be in favour of further sampling, because the result would still be inconclusive. However, should further testing be inconvenient or too expensive it may be preferable to let production proceed and to test a little more frequently than usual, but in this case staff are warned that the results are still inconclusive, and that it is not known for certain whether a change in production is taking place or not. On the other hand, if the second test yields so few "defectives" that the total number of "defectives" in the combined sample is less than five, it can be agreed that production is proceeding normally. Should the "defectives" in the compounded

sample be eight or more the result would confirm that conditions in the factory are not stable, and hence positive action should be taken. If further samples be taken the results should always be compounded and considered in relation to a new set of limits determined by reference to the fundamental data given in Fig. 8.

A refinement. Two-way control chart for "defectives."

Now let us consider a refinement of the foregoing procedure, which I think will demonstrate the help obtained from thinking statistically. Let us construct two charts and plot the number of articles in the sample which fail the "GO" gauge on one chart, and the number that fail the "NOT GO" gauge on the other chart. Assume that the manufacturer's aim is to make the product midway between the gauge dimensions. Under this condition, working at a level of 1 per cent total rejects, 0·5 per cent would fail the "GO" gauge and 0·5 per cent fail the "NOT GO" gauge. That is, the average proportion of "defectives" which will appear on each chart is 0·5 per cent. From Fig. 8 compile Table 2, which is similar to Table 1, but 0·5 per cent, 1 per cent, and 1·5 per cent "defectives" in the bulk replace 1 per cent, 2 per cent, and 3 per cent respectively. Table 2 shows that two or more articles per sample will fail to pass each of the gauges once in 10 samples; three articles would fail to pass each of the gauges only once in 100 samples and would, therefore, if found, indicate a possible change in the product because, suppose the product changes so that the proportion of "defectives" is 2 per cent, then the chance of obtaining three or more "defectives" is sufficiently increased.

TABLE 2.

"Defectives" in sample of 100 articles.	Proportion "defective" in bulk product.		
	½ per cent.	1 per cent.	1½ per cent.
	Approximate proportion of occurrences in repeated sampling.		
0	12 in 20	7 in 20	4 in 20
1 or more	8 ,, 20	13 ,, 20	16 ,, 20
2 ,,	2 ,, 20	5 ,, 20	9 ,, 20
3 ,,	1 ,, 100	1 ,, 13	1 ,, 5
4 ,,	1 ,, 600	1 ,, 50	1 ,, 15

If there are engineering reasons for assuming that a change in dimension is likely to arise mainly from tool wear, then a drift in size would be expected rather than an increase in the spread in dimension. In such a circumstance it might prove valuable to use

the two charts, and so to set the machine initially that 1 per cent of the product would fail one gauge but few fail the other gauge. As tool wear occurs the number of "defectives" plotted on one chart would tend to reduce, whilst the number on the other chart would tend to increase. Thus, information would be continuously available and production could be stopped at any time when too many "defectives," say three, are appearing on the second chart. A further common-sense comment can be made, namely, if the manufacturing unit is complicated then erratic behaviour might be expected. This would probably show itself by the plotted points dodging about from the 2 or 3 level in one chart to the 2 or 3 level in the other. Such events would be a positive indication that tool wear was not the principal factor governing change of size, but that some uncontrolled part of the manufacturing unit was giving rise to change in size.

After some experience of thinking in terms of statistical probability the engineer will find it a good exercise to consider the data given in Tables 1 and 2 coupled with the use of two charts, to convince himself that this refinement is more sensitive in detecting a change in average dimension than an increase in the spread of dimension, for a definite proportion outside the "GO" and "NOT GO" limit. The essential facts are :—

If the spread has increased so that one "defective" will be found on the average on each chart, then Table 2 shows that three "defectives" will be found once on each chart in 13 samples; if a drift in size has occurred so that on the average two "defectives" will be found on one chart only, then Table 1 shows that three "defectives" will be found on this chart once in three samples.

Study of Data Derived from Measurement

So far we have not introduced a direct measurement of variability nor utilised actual measurement, but have relied solely on failure to pass limit gauges. The introduction of measurement on some continuous scale makes it possible to use a real measure of variation. All the frequency distributions shown earlier simulate a distribution which can be demonstrated, both experimentally and mathematically, to arise when a large number of independent disturbances act at random. This distribution is illustrated in Fig. 11 and is known as the "Gaussian" or "Normal" distribution. The curve can be defined algebraically by two simple quantities or parameters : (*a*) the average value of all the results, (*b*) a quantity the statistician calls the "standard deviation" of the results. The latter is a direct measure of variation and is obtained by adding together the squares of the differences between each result and the average of all results, dividing by the number of observations and

then extracting the square root. Electrical engineers will recognise that this corresponds with the root-mean-square value of current or voltage for an Alternating Current circuit.

The average value and standard deviation of bulk data are usually represented by "$\overline{X}$" and "σ," whilst "$\overline{\overline{x}}$" and "s" are used for the corresponding sample parameters. These quantities are related by definite laws, and in addition definite proportions of the distribution curve lie outside limits expressed in terms of the standard deviation, and these have been tabulated. These relationships and data are the basis of everyday application of statistical methods to the study of test results. One of the most useful of these laws is: If samples of the same size are repeatedly selected from a bulk then the standard deviation of the average values of the samples is equal to the standard deviation of the bulk divided by the square root of the number of articles in each sample.

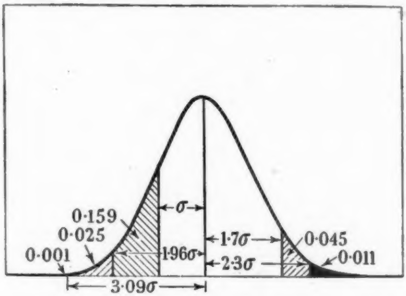


Fig. 11—Gaussian Distribution.

In Fig. 11 the proportions of the distribution curve that lie outside certain multiples of the standard deviation are indicated. Some of these are readily memorised and are of considerable utility. For example, lines drawn at $1 \cdot 96 \times \sigma$ either side of the average value cut off 1/40th of the observations at each tail of the distribution curve, that is 19/20ths of the observations lie between the lines. Similarly two lines drawn at $3 \cdot 09 \times \sigma$ cut off 1/1000th at each tail of the distribution curve. These proportions only hold for the ideal distribution, but sometimes, as in the case of the strength of cotton shown earlier, there is appreciable deviation from the ideal or "Gaussian" distribution. In such cases the proportions of the distribution curve cut off by lines drawn at various multiples of the standard deviation do not agree with those referred to above and given in statistical tables. However, it is easy to show that whatever the distribution the average result for

small samples chosen at random from a bulk whose distribution is " skew " or " non-Gaussian " rapidly tends to become " Gaussian " as the size of the sample increases. Therefore, in practical cases of this kind, or when knowledge of the distribution is scanty, the engineer should concentrate attention on the average result of samples containing, say, four to ten articles. This property of average results is illustrated in Fig. 12, where data are given which were derived from practical sampling from results having a distribution represented by the curve at the top of the figure. It will be noted that the average results for 200 samples of five articles are distributed reasonably closely to the " Gaussian " form, and that when the sample quantity is increased to 10 the approximation is

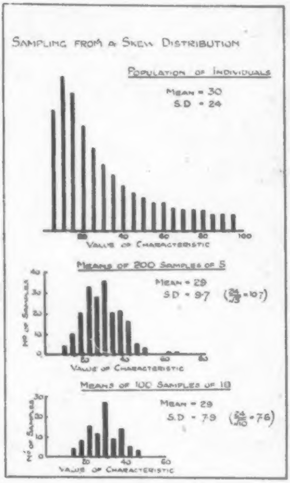


Fig. 12.

closer. The standard deviations for the two groups of sample averages is also seen to be in reasonable agreement with the result expected on theoretical grounds and referred to earlier.

Control chart for average values

We can now consider the construction of control charts for average values derived from samples containing a few articles. When small samples are selected from the same bulk their averages will differ due to the differences between the individuals, and some allowance for this must be made when studying the results.

In Fig. 10 data were given which made it possible to determine the 1 in 40, and 1 in 1,000 limit values for the number of " defectives " in a sample.

The corresponding limit values for the average value of samples selected at random from a bulk are obtained from the data given in Fig. 11.

Thus, if " n " is the number of individuals in the sample the 19/20 limits (1 in 40 limit each side of the bulk average) are :—

$$\bar{X} \pm 1 \cdot 96\, \sigma/\sqrt{n}$$

and the 499/500 limits (1 in 1,000 each side of the bulk average) are :—

$$\bar{X} \pm 3 \cdot 09\, \sigma/\sqrt{n}.$$

Note.—If X and σ are not known from accumulated data, then for the purposes of introducing a chart they can be estimated from a minimum of 10 samples of 5 to 10 articles per sample, selected from representative production.

Example Illustrating Relative Sensitivity of Various Methods

In the foregoing we have considered in detail the problem of detecting a change in the average dimension of a product corresponding to an increase in the proportion which fails to pass " GO " and " NOT GO " limits from 1 per cent to 2 per cent, the change being due to a drift in the average dimension and not to an increase in the spread of dimension.

We have seen that when testing a sample of 100 articles with the limit gauges, *a total of four* or more " defectives " will be found slightly less often than once in 40 samples (Fig. 10), but that if a drift in dimension of the kind postulated above occurs, then four or more articles are likely to fail the gauges *once in seven* samples ; this criterion being used to give *warning* that a change has taken place.

As an example of the use of the statistical principles reviewed in this lecture let us answer the following question :—

How many articles should constitute each sample selected for measurement and test against 19/20 statistical limits, in order to obtain the same sensitivity in detecting a drift in size as that secured by the rejection of four articles by the limit gauges in samples of 100 articles ?

As before we assume that the production is normal when the average dimension of the product is centrally placed between the limits, and 0·5 per cent is rejected by each limit gauge. These gauges correspond to limits placed at $\pm 2 \cdot 58\, \sigma$ from the average value of the normal product (see Tables ref. 2). If the average value drifts until 2 per cent are outside the original limits, the

statistical tables show that these limits are now $2 \cdot 08\ \sigma$ and $3 \cdot 08\ \sigma$ either side of the average for the deteriorated product, *i.e.*, the average dimension of the product has changed by an amount equal to $0 \cdot 5\ \sigma$.

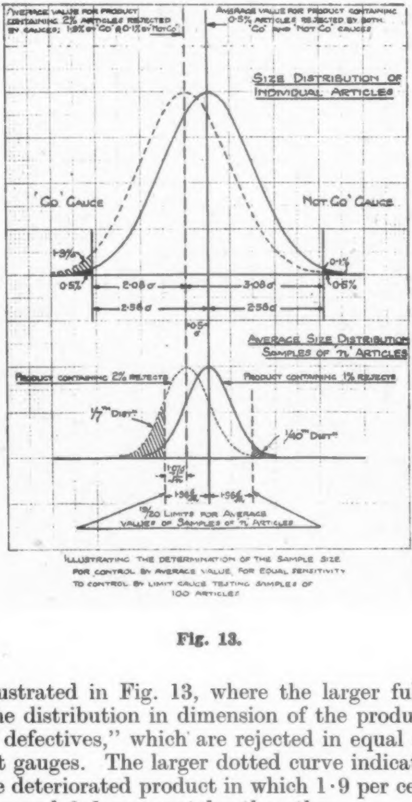


Fig. 13.

This is illustrated in Fig. 13, where the larger full-lined curve represents the distribution in dimension of the product containing 1 per cent "defectives," which are rejected in equal quantities by the two limit gauges. The larger dotted curve indicates the distribution of the deteriorated product in which $1 \cdot 9$ per cent is rejected by one gauge and $0 \cdot 1$ per cent by the other.

When samples containing "n" articles are measured, we have seen that the standard deviation of the average values for these samples is $\sigma/\sqrt{n}$. The full and dotted smaller curves illustrate the distributions of these average values for samples selected from the original and deteriorated product respectively.

Concentrating attention on the small full-lined curve we can determine the position of the two limit values outside each of which one average value will fall once in 40 times, if repeated sampling is done. We have seen that these limits are placed $1\cdot96\ \sigma/\sqrt{n}$ on either side of the original average dimension of the product.

Finally, we wish the lower of these two limits to cut off the same proportion of the tail of the smaller dotted curve as the probability that four "defective" samples will be found by the limit gauges in a sample of 100 selected from the poorer product, *i.e.*, once in seven samples (Table 1). Statistical tables show that 1/7th of the smaller dotted distribution curve will be cut off if this lower limit line is $1\cdot07\ \sigma/\sqrt{n}$ from the average value of the dotted curves. By reference to Fig. 13 it is obvious that this condition is met when

$$1\cdot96\ \sigma/\sqrt{n} = 0\cdot5\ \sigma + 1\cdot07\ \sigma/\sqrt{n}$$

$$0\cdot89/\sqrt{n} = 0\cdot5$$

$$n = \sqrt{1\cdot78} \text{ or } n = 3\cdot2 \text{ approx.}$$

That is, the average value derived from measuring a sample of four articles considered against limits placed $\pm\ 1\cdot96\ \sigma/\sqrt{4} = \sigma$ approx. either side of the average dimension of the normal product will be rather more sensitive than using the failure of four articles in samples of 100 to pass the limit gauges.

Following a similar argument it will be found that approximately the same result is obtained if the comparison between the two methods is based on the occurrence of three "defectives" in the sample of 100 as the criterion indicating the presence of a change in the product. The probabilities of three "defectives" being found in samples selected from the original and deteriorated products are, once in 13 and once in 3 samples respectively (Table 1).

Similarly if separate charts for both "GO" and "NOT GO" rejects are used then, when the product has changed in the manner prescribed above, three "defectives" will be found on one of the charts once in every three samples, and a calculation will show that samples of nine articles measured, and their average values tested to limits $\pm\ 1\cdot96\ \sigma/\sqrt{9} = 0\cdot65\ \sigma$, will give the same sensitivity.

Finally, if measurements of the required accuracy can be readily made it may be desirable to increase the number in the sample tested so as to obtain greater sensitivity, which can be expressed either as (*a*) detecting a smaller shift in the average dimension with the same probability.

(*b*) Increasing the probability of detecting the change postulated in the example.

For example we have seen that the average value of samples of four articles can be used to give a probability of 1 in 7 of detecting

the prescribed change in the product. By using 15 articles in the sample it would be possible to

(*a*) detect a shift in the average dimension corresponding to an increase from 1 per cent to 1·2 per cent rejects to the "GO" and "NOT GO" gauges, with the same probability (1/7);

(*b*) increase the probability of detecting the prescribed change from once in seven to once in two.

I do not propose to extend further the scope of this lecture. Normally the next step is to ask questions such as "Can I use these methods to direct efforts towards reducing the 'defectives' from say, 1 per cent to 0·5 per cent?" The answer is "yes," for there are statistical procedures which enable you to decide where best to sample and how best to sub-divide the test data, using technical knowledge of the production procedure. This will aid in determining at what stages in the factory variability is introduced. That is, in the language of statistics, the methods combined with engineering, physical, or chemical knowledge assist in transforming chance causes into assignable causes. This is the first and necessary step in all efforts made to reduce variation and so to improve quality and/or cost.

I hope I have convinced you of the power of this tool if properly applied. Like all tools, skill in its use can only be achieved by practice. Attendance at lectures or book study alone cannot give skill; personal handling of practical examples is essential. You will find such examples more interesting than the solution of cross-word puzzles or the filling-in of football pool coupons. Once "bitten," engineers will find it immensely interesting to watch the working out of the methods in the factory, and will rapidly learn to appreciate the methods as valuable friends.

Discussion

Mr. W. Puckey (*Chairman*): It has been said that statistics to the engineer are like a lamp-post to a drunken man, for support rather than illumination, and I feel that the illumination arising out of Dr. Dudding's most interesting talk will begin to dawn on us more in a few days' time, when we have had an opportunity of thinking more fully about this matter than we have been able to do at the moment. With that object in view, the Institution is most anxious to give the fullest publicity to this very interesting lecture, and to give all its members and others interested a full opportunity of weighing up the pros and cons and attempting, we hope, to put into practice some of the theoretical points which have been brought forward.

Mr. F. H. Rolt (*Director of Gauges, Ministry of Supply*), who opened the discussion, said: I should like to thank you for your kind invitation to attend this meeting. I am not a member of the Institution of Production Engineers, but I have always taken a very close interest in their proceedings.

The question of control inspection is one which at the moment is assuming great importance. The inspection of munitions is a great undertaking. It is obviously important from the point of view that the munitions which we supply to the troops should be of the right quality, and also owing to the magnitude of the task of inspection. It absorbs a great deal of labour not only in the actual operation of gauging but also in the manufacture of the gauges themselves. The subject of control inspection is therefore important from the labour side, and I would say quite deliberately I do not think that, in the past, it has had the attention it should have had in connection with the inspection of munitions. Dr. Dudding has studied this subject as an officer in a factory who is responsible for the production of work of good quality. That at the same time involves the question of inspection. He has had the responsibility of seeing that the work which is produced is good. His object has been not to reject the work after it has been made, but to see that whilst it is being manufactured it is being made within the prescribed tolerances. In other words, he has been operating a system of control inspection.

In ordinary engineering production we have the tool-setter, and I venture to say that that man is, in a sense, a control inspector. He is the man who is controlling the size of the product coming from the machine; he is the man who gives you either good or bad work. The inspector comes along afterwards and sorts it out. I would ask whether you think that the tool-setter has been properly backed up in his duties. I would go so far as to say that the inspection departments might very well consider diverting some of their

labour from final inspection on to what one might call machine-inspection. Those are just a few words in general terms.

Dr. Dudding has shown us this afternoon a number of charts illustrating the effects of the laws of probability, and how they tend to heap up the output in the middle of the limits principally with regard to products associated with his own line of work. In this connection, I thought it would be of interest if I showed you a few examples which I have studied myself in connection with limit gauges. The distribution of work within its limits is one thing, but one might well ask whether gauges follows the same law, since here we are getting to a much higher grade of manufacturing. I want to show you that what Dr. Dudding has told us about the distribution of output in the case of glass tubing and so on apply equally well to very high-class engineering work.

I have a few slides here which show the results of the measurements of a number of screw gauges which were produced in quantities. The tolerance which was given to the gauge maker was only six ten-thousandths of an inch. The gauges were measured after manufacture, and the numbers which came within each ten-thousandth of the tolerance plotted. It will be seen from

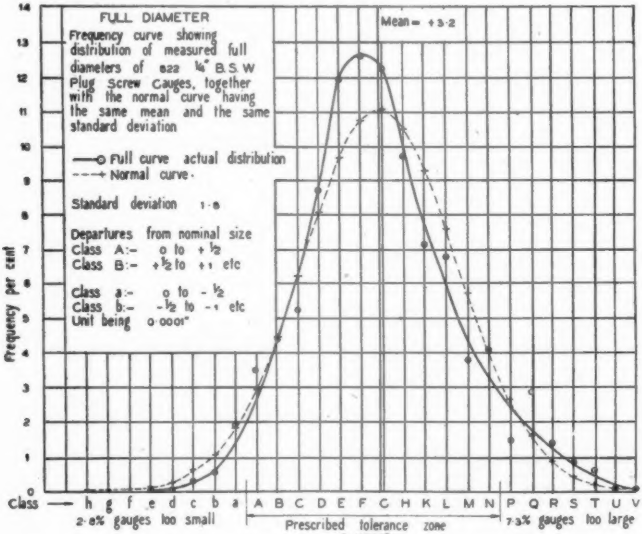
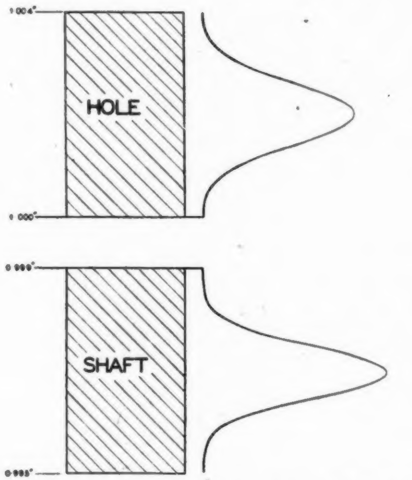


Fig. 1.

Fig. 1 that the distribution of those gauges follows very closely indeed the theoretical law, which is represented by the dotted line on the chart.

There is one point which has occurred to me when I consider such a chart as this. Suppose the gauge manufacturer were given another one ten-thousandth of a inch tolerance at each end, and he makes gauges to those enlarged tolerances, but when the gauges are inspected they are passed and rejected to the *original* tolerances, should we get a more economical output of gauges for the amount of labour that is put into them ? That is a question on which I should like Dr. Dudding to give me his opinion.

Now I come to another point, associated with the design of work.



LIMITS DIAGRAM DISTRIBUTION CURVES

Fig. 2.

The two charts shown in Fig. 2 will be recognised by those familiar with British Standards Institution charts on limits and fits. The upper one represents the tolerance zone for a hole, and the lower one the tolerance zone for a shaft. The hole is intended to be produced between limits of 1 in. and 1.004 in., and the shaft between limits of 0.999 in. and 0.995 in. It is quite clear that if the largest shaft meets the smallest hole there will be a clearance of 0.001 in., and every shaft will go into every hole, in other words, 100 per cent interchangeability is being provided for. On the

other hand, when the smallest shaft meets the largest hole there will be a clearance of 0.009 in. Putting it another way, suppose a designer, in laying down limits for a shaft and a hole, knows from practical experience that he must have a clearance of 0.001 in., and that he cannot tolerate a greater clearance than 0.009 in., he starts with that as a basis, and takes the difference between the two, 0.008 in., and divides it into two parts, giving 0.004 in. tolerance to the shaft and 0.004 in. to the hole. That is the tolerance which he puts down on the drawings, but in doing so it seems to me that he is entirely disregarding the laws of probability.

According to Dr. Dudding and statisticians, the frequency of distribution of the manufactured shafts and holes within their tolerances is as shown on right hand side of the diagram. The bulk of the shafts and holes will be near the middle of their tolerance: there will be very few at the tail ends. If it is 1 chance in 1,000 that you get a shaft right on the top limit, and 1 chance in 1,000 that you will get a hole on the bottom limit, I would like Dr. Dudding to tell is what are the chances of those two 1 in 1,000 chances happening together. I should think myself that it would be of the order of 1 in a million.

The point that I wish to make is that it is not just a simple geometrical problem to lay down tolerances based on certain prescribed clearances, maximum and minimum. I consider that the effects of the laws of probability should definitely be taken into account in the laying down of limits and tolerances, so that the production engineer is provided with the largest possible tolerances consistent with the mechanism operating satisfactorily.

Dr. Dudding told us that if we assumed certain things with regard to the production of a component, we could then apply certain rules which would enable us to study the quality of the product as it comes from the machine. In practice, there are often a number of machines working on one product, and the whole output may be collected together before it is inspected. I think that Dr. Dudding will agree that, in order to apply his rules and criteria to the problem, it is more desirable in such cases to keep the product of each machine separate, so as to keep a stricter control of the quality of production of each machine.

Dr. Dudding referred to the question of tool wear, which is associated with almost every type of engineering production. He has shown us that by special application of his charts we can still exercise a control on the product, taking account of this slow drift of size due to tool wear.

I quite agree with Dr. Dudding that statistical control is a subject which at first sight is difficult to understand. I feel that one can only gain confidence in it by taking a number of products, measuring

them and drawing a few charts, thus proving to one's self that the laws of chance are really definite. I think that that is the only way in which we can approach this problem; we must get practical and personal experience of it ourselves. In this connection, I would suggest that, if a product is at present being inspected 100 per cent, let it also be inspected only 10 per cent. Then from the results of the more limited inspection, conclusions could be drawn on the basis of what Dr. Dudding has told us, and these conclusions could be checked against the results of the 100 per cent inspection. Theory says that the results should check satisfactorily, but it is more convincing to prove it one's self, and thus gain personal confidence in the application of the principles of control inspection.

MR. C. H. STARR (*Associate Member*): There are two points which I should like to raise. First of all, I understood Dr. Dudding to say that one could not find this in books. It is probably correct to say that one cannot find the actual application in very many books, but there are one or two useful small pamphlets of which he probably knows published by the American Telephone and Telegraph Company. I wonder if he could tell us of any other reference books bearing directly on this work?

Secondly, all this business seems to be very "sure-fire" and very satisfying when applied to quantity production work to a continuous process, a stable process but I should like to know more about its application in the case of small quantity batches. Take the case of inspecting small consignments against a purchasing specification. One may have to deal with articles ordered in total quantities of say 2,000, 3,000, 5,000, and even up to 10,000, coming in in batches of 500 or 1,000 or 2,000 at a time, possibly at one time of the year from one supplier and at another time of the year some months later, from a different supplier altogether. In other words, you have several unknowns and your quantities are small from the point of view of establishing averages and getting your statistics on bedrock. Can sampling be very precise under such conditions? One seldom wants to do 100 per cent inspection on products bought outside, if they are not absolutely vital. Just how scientific can statistical methods be when sampling small consignments under unstable conditions.

DR. DUDDING: There is one point of interest to which I have already given attention because it raises one of the matters which every engineer will have to consider. I have translated the little problem which we considered together into dimensions. I took $\pm 0''\cdot003$ as the sort of tolerance that there might be allowed for the "GO" and "NOT GO" gauge, that is, $0''\cdot006$ altogether. If you remember, the figures which I gave were $2\cdot58\,\sigma$ as the limit,

which cut off the 0·5 per cent tail corresponding to 1 per cent defective in a controlled product ; therefore σ would be $\frac{0''\cdot003}{2\cdot58}$. Hence the control limit for the average result if we measure nine is obtained by dividing $\frac{0''\cdot003}{2\cdot58}$ by $\sqrt{9}$ and multiplying by 2. This is equal to about 0″·0008. Therefore we wish to impose on an average of nine random selected samples control limits of $\pm$ 0″·0008. Can we measure with that precision ? We obviously have to measure to an accuracy of 0″·0001 or 0″·0002 on the work. An indicating form of instrument set up on a master gauge which enables errors to be read direct might make it possible to do so, and the question then arises : Is it easier to make the gauges and wear them out testing 100 samples per batch of say 1,000 pieces, or to make a small measuring machine which would measure nine samples to this precision ?

This is a question which arises in Mr. Rolt's question. He asks : what would happen if he gave additional tolerances ? He wants to establish controlled manufacture. In that case the first thing that I should want to do would be to introduce a system by which samples of the gauges were measured, and the average result compared against limits on the average of the sample, to establish that the maker was controlling his product. Otherwise, if he is given more tolerance he may get more sloppy, and instead of having 10 to 17 per cent outside existing limits the figures would climb. Whether you would then increase your rejections by 5 per cent but increase the total production by 15 per cent I could not predict, as it would depend a good deal more on the man than on the statistics.

MR. ROLT : It is a matter of trying it out.

DR. DUDDING : Yes, but you must do something to curtail the human tendency to get sloppy through being given an extra ten-thousandth by insisting that the man must test nine per 100 say, and show that they lie within much closer limits than those prescribed for individual gauges. This is, you would tie him down to controlled production and perhaps secure the end you have in view.

I agree with Mr. Rolt about the shaft and hole. There are too many things designed on the drawing-board without any thought as to what is ultimately going to happen. If you can establish that the manufacturer is controlling the processes for making the shaft and the hole then, taking the middle size for the hole and the shaft as objectives, you could provide a control chart for sampling to satisfy yourself that he was controlling production to some

prescribed degree. The question raises engineering questions, but control by this means may be worth while, because it may result in 66 per cent of your shaftings, say, going together with a clearance of about 0″·002, a few either failing to assemble or having rather larger tolerances, but this may be a good deal better than the present situation, where many of them may have clearances of 0″·005, 0″·006, and 0″·007.

The basis must always be to establish controlled manufacture, and that leads me to answer one of the questions raised by Mr. Starr. The whole object of this work is to make inspection a part of production and not to make it somebody's profession to throw out work after it is made, and therefore to make sampling of small consignments by the customer a sheer waste of effort. To do so is a national waste and a crime when, in many factories, there is controlled production. There is evidence that you purchase goods on the market with absolute confidence that they will conform with some specification with which they are made to conform. The spending of £10 to test a £50 order is one of the things which this work is intended to prevent. It is one of the aims of this work to avoid this practice of making purchasing specifications the be-all and end-all of everything and to introduce systems of inspection in production which reduce specifications merely to occasional use. Purchasing specifications must not wholly govern the relationship between consumer and producer.

As to textbooks I did not intend to infer that there were none to be had. I called attention to the amount of work which has been done to provide engineers with all the necessary information. Textbooks on this subject are generally difficult to read because they are written by a specialist in some field and the examples chosen are not familiar to the engineer. However, the British Standards Institution, by publishing a pamphlet on the subject, has done a good deal to help, and there has just been published in America a very useful book (see ref. p. 23). A very good book published in England is that one by Tippet, a physicist by training who, after some experience in the cotton industry, was trained in statistics. This book is one of the most readable of the books available. But reading books is not what is wanted; you must use these simple statistical relationships yourselves.

Mr. P. Good (*Director, British Standards Institution*): Mr. Starr's question went to the bottom of the reasons for my taking an interest in this subject. Some years ago he was wanting to take delivery at more or less regular intervals of products which conformed to a standard, and not to be troubled with those which did not conform. This is a widespread want throughout industry today and has been for years. We ourselves became interested in this subject, probably largely owing to the incentive of Dr. Dudding

and Dr. Paterson, when we were bothered with the problem of securing that the general outflow from a factory conformed to a British standard specification. The British Standards Institution has the responsibility for marking products which conform to a specification, and our problem was how to secure conformity without any elaborate form of inspectorate or elaborate system.

It became clear that the real method of securing general and proper conformity to a specification must be that method which responsible people who are doing production would be using to satisfy their own management that the goods did in fact conform. It was found, however, that in a vast number of cases that form of control which was applied internally was not so adequate as might have been hoped ; but the experiences which Dr. Dudding and his colleagues were able to bring to our aid showed that, by the proper application of statistical knowledge, systems of control could be introduced which would give the required degree of assurance that the product in fact conformed without adding to the difficulties of production. I am not a statistician, but I have heard a number of lectures, several of them given by Dr. Dudding and his colleague Mr. Jennett, and I have seen the system introduced into various factories. I am quite satisfied that it does offer a remarkable tool for those concerned with producing precision or uniform quality goods, and it will, I feel sure, come to be recognised as the correct method of control in a very large number of factories. I can certainly strongly commend the study of it to all those concerned with inspection.

I thought that the lecture this afternoon adopted a new angle of approach ; I have not heard Dr. Dudding and his colleague approach the subject before in this way, and I think it gave a very interesting picture of an approach which should in war-time, at all events, greatly simplify the work of those who are desirous of rapidly acquiring some knowledge of the subject. I hope that it will be printed quickly. The British Standards Institution will shortly be issuing another pamphlet on this subject, which will be based very largely on the lecture we have heard this afternoon ; but you will get it first in the Proceedings of your Institution. I hope, as I say, that it will be issued very quickly, because I think that from it you will readily get a working knowledge of what you have to do, and you can then make a further study of the subject.

The B.S.I. has been primarily concerned with the contıol of a general good average quality ; and I was very impressed not long ago with the possibilities of this method when we were faced with a somewhat new problem. A group of firms in this country were organising a plant in another part of the world for the production of a commodity which is produced in tens of thousands, and we were asked to investigate the problem of devising a control in order

that we might be able to license the factory to mark their goods with our mark as a guarantee that they conformed to specification. This investigation, in which Dr. Dudding and his colleague assisted, proved how much less work had to be done to secure effective control than I should have believed likely. This case alone satisfied me as to the immense value of a study of this subject to those involved in the mass production of commodities which are required to be up to a definite standard of quality.

Mr. L. Palmer (*Chief Inspector, Standard Telephones and Cables, Ltd.*): I am chief inspector of the Southgate plant of Standard Telephones and Cables, and have listened with pleasure and with admiration to Dr. Dudding's excellent lecture on sampling inspection. In my job sampling is practised, and we have experimented with a number of systems at different times; while the question of quality control is, of course, continually under review. Indeed, since the war the numerous gentlemen whom we have had in our plant from the Service departments would soon have pulled us up if quality control were at all lax, and I am sure that that is the general experience.

As regards the question of sampling there is one aspect of it which is of great value, and that is in providing a check on products coming in from another source of supply; and where some criterion of quality is necessary in order to ensure that the product is fit to put on the assembly lines. That point was raised by a previous speaker, Mr. Starr. It is of importance, because it is not merely a question of going over previous ground; there is such a thing as deterioration, particularly in some types of electrical equipment, and it is necessary, if an article is held for any length of time, to have some rapid and efficient system of determining the general quality of the product. Without exaggeration I should say that it saves some 75 per cent in "nobs" alone, if I may use that term in speaking of the examiners.

Another point I should like to mention and about which I should like to ask Dr. Dudding for information, lies in the mechanical field of inspection. There, in our case, we have not had much success with sampling methods. I am referring particularly to fast-moving products coming from an automatic machine. Let me take the insert as a common example with which many of us will be familiar. You may have inserts produced at the rate of 1 in 7 seconds, and it would be of great value if some simple system of controlling quality were available instead of having to collect it in batches and then inspect it in detail. We have tried, in my own department, methods of taking samples directly from the machine, but we have not applied what may be described as the scientific method of sampling because the rate of production is so rapid. Much the

same applies to the other products of the machine shop, and particularly to press and mill details. In those cases the difficulty is not so much a question of the rate of production as of the variability of the product. It may be due to the fact that I am not a statistician, but the extreme variability seems to me to defeat the practice of sampling. In the cases in which we have found sampling so successful, variability has, of course, been excluded by the previous examination of the product at the source of its manufacture.

I think that Dr. Dudding has made out a very strong case indeed for sampling to be applied to many of the lines of munition production, because there, at least in the experience of my company, we find an almost duplicated inspection by the Service departments on top of our own 100 per cent inspection. I suggest that this affords an almost ideal case for treatment by sampling. I should be glad to hear Dr. Dudding's opinion on this point. There are many cases of this sort to-day, and I think that there would be a great economy in the handling and inspecting of the goods if sampling were adopted.

I was very impressed indeed by Dr. Dudding's remarks about the value of a statistician in the works organisation. It made me think that a combination of the statistician with the inspector would perhaps be a complete answer to the most astute board of directors, and I make my colleagues a present of that thought! Finally, I should like to say that I am most grateful for the opportunity of listening to Dr. Dudding.

Dr. Dudding: Mr. Palmer has raised two points on which I should like to comment briefly. The first concerns this question of material from another source of supply. Many firms have much of the required evidence already, but they do not put the control lines on the plotted charts. If they did, the standard to which they are working would be known, and 100 per cent inspection of the work would in many cases be only a waste of effort. In its present form, however, the information does not give the degree of confidence which is needed. The best safeguard in the long run, whatever overriding sampling and testing is done, is to try to insist on seeing that the supplier has controlled production. You would have very much less inspection to do if he could produce control charts and was able to demonstrate that the material supplied went through, say, in May and June, when conditions of manufacture were stable and results up to the required standard. He could show you the raw material checks and the checks made at various stages, and you could then do exactly what Mr. Good wishes to do. You could rely on inspection of control charts and need not do more than make an occasional sample check against specification, just to make sure that something had not slipped up somewhere.

The second question is not quite clear to me as I do not know what variability Mr. Parker refers to in his machine shop problem. Do you mean that you change the type of product coming off the machine ?

MR. PALMER : Variation in limits.

DR. DUDDING : That appears to be a straightforward problem. We have many machines producing 500,000 articles in a week of 160 hours. That is a case where articles are coming off the machines very fast and we have a regular system of selecting samples, and the results are logged on control charts, and we know what is happening whilst production proceeds. It is the same with glass tubing. One of the most subtle troubles we have experienced occurred some years back with glass tubing, due to the presence of extremely fine crystals which will bring the strength down enormously. They are difficult to find even with a microscope even when you know that they are there ; but they will show up readily on the breaking strain test. The material is sampled, eight pieces per shift being the general rule, and any loss of quality is soon discovered. Variability can be checked only by the control chart method and whether you test once an hour, once a shift or once a day depends on the job. We usually start by testing too frequently and then, when we see that production is settling down we can reduce testing, because we know better what we are handling. When introducing control chart methods to a new job the first thing to do is to use technical knowledge to guide where to start testing, but above all to start and then adjust sampling and testing procedures as experience is gained. I am not going to commit the unpardonable sin of prescribing how to tackle a job that I have never studied, but I am quite sure that statistical methods can assist in some degree all manufacture.

The CHAIRMAN : There have been several broad hints that the Government inspection departments might effect a considerable economy in inspection methods by adopting the sampling procedure and statistical methods. I am glad, for that reason, to find that we have a number of representatives of the C.I.A. here. I do not know whether anyone officially represents the A.I.D., but Sir Frank Gill, who is present, has had a good deal of work to do in that direction. Perhaps we could hear the point of view of anyone who knows the views of the Government inspection departments, because what one does in any organisation can go only so far as the Government overriding authority will let it go, and it would be, I feel sure, very interesting to the meeting, and certainly to me, to know the views of the official Government inspection departments on this problem.

BRIGADIER E. A. WOODS (*Chief Inspector of Armaments*) : We deal altogether, I think, with some 8,000 to 10,000 firms. We

have discussed this matter at the Ministry and I feel that, although we can put it to use, it is more a method for manufacturing control than for Government inspection. We do not concern ourselves with production control—that is the job of the firm.

Mr. Rolt said, I think, that inspection in the end comes down to the tool-setter. After all, he is the foundation of inspection, and really where things go wrong in quantity production is on the machines. The production of small parts seems to me one of the cases where it is better to use gauges—I imagine "GO" and "NOT GO" gauges—or keep statistics and inspect every now and then by measuring; but it does seem to me that we have to get down to the fundamental thing on the machine.

Mr. Palmer referred to the duplication of inspection, twice over 100 per cent. I deal with guns and munitions, and everything that is part of a gun or munition has to be inspected 100 per cent by someone. It is not a question of running off. If you are dealing with electrical machinery, if I may suggest it, then if you do run off in one part a bit out of dimension the machine will still work, although it may be less efficient. If you are dealing with a fuse, however, and you run out in one dimension you may blow up a gun's crew. So far as we are concerned, therefore, I do not think that for actual inspection for acceptance a statistical method will apply to quantity production of, say, parts of a fuse, because statistical inspection will show you only, possibly a little late and not with certainty when a thing is going wrong, and the parts that have gone wrong may by then have been built into a fuse, and the gun's crew may be blown up. I do not think, therefore, that we can apply it in place of inspection.

We are trying to avoid this duplication of inspection, and I think I can say that where we have control we either inspect ourselves or do control inspection. Where firms have an efficient inspection department we take a percentage check, which is usually 10 per cent or below it. We do not make any attempt to say that that inspection is a representative sample; we are inspecting not the goods but the firm's inspection and, if we find one gauging error, then the whole of the goods represented by that batch are thrown back on the firm.

We can, however, apply the statistical method to certain things, and we are interested in it. We occasionally come across cases where we get a very large and unexplained percentage of gun fuses going wrong. It may or may not be a difficult investigation. We have asked the people who have been studying this to propose a line of investigation to say what data we should accumulate, because that is one of the claims made for this system, that it will give you earlier indication of what is going wrong. We have asked to have a scheme submitted to us and, if we can, we will

put it into operation, take the data and see how it works. It is also applicable to certain problems in connexion with cordite.

There was one point which Mr. Rolt mentioned which made me a little frightened, namely when he suggested that he might be able to use a little more of the probability curve and get a bit more through the inspection. I do not know whether I understood him correctly there ?

Mr. Rolt : No.

Dr. Dudding : Mr. Rolt's point was that he was hoping, by still keeping the manufacturer under control, that by giving him a little more scope he would ultimately get more gauges, although he finally tested to the same limits. I think it is worth trying. You cannot tell until you try.

I should like to comment on points that the Chief Inspector has made. He has mentioned that he uses the control of the factory where he is satisfied of the efficiency of the control department. How does he judge that efficiency ? I would judge the efficiency very much on whether they keep control charts throughout their work. I should not be impressed by " efficiency " which depended on the scattered use of gauges. I should not feel very safe with that, but I should feel very safe if I knew that their inspectorate system was fundamentally grounded on sampling and checking to control limits at various stages throughout the production. In our own factory we have a certain number of these charts just outside the manager's office, and every night the man responsible for running the department sees the figures go there himself and sometimes has to put them there, which is even better for him. He plots the results of the inspection going on in his department each day. When you have that system you can have confidence in the inspection ; and how far you can allow that to govern your overriding inspection does, of course, depend on such matters as have been mentioned—the safety and welfare of other people. It is not disputable, however, that whatever you do in your final overriding inspection you cannot do the one thing that you want to do, which is test every fuse and make sure that it will not blow up a gun ; you are always forced to infer that the fuses will be all right because you have yourself 100 per cent inspected certain parts to certain limits.

I feel that a problem such as that could be dealt with because, if you could get controlled production, you might find that many firms would give you a guarantee to work to limits inside the present limits which you are imposing. Your present limits are largely imposed on the result of long experience, and you do this 100 per cent inspection just to make sure that, with a manufacturer who does not know quite what he is doing, you can throw out the outfalls which experience has shown may be the cause of difficulty.

The Chief Inspector is quite right when he points out that an Inspectorate cannot take the responsibility of introducing a system of controlling quality of the kind suggested. It is certainly the duty of manufacturers first to introduce the system and then to ask Inspectorates to take cognisance of what they are doing, and to use the data provided to assist them.

I am not expecting that we shall get this work going 100 per cent during the war. In my own company in fifteen years the use of the methods have not become universal, in spite of the amount of attention given to it and the many devices used to convince technical men and salesmen that they produce the desired result. We shall not, therefore, see a change overnight; but it will be something if people will pick out what they feel to be the "safe" problems and begin to work on them, because I am sure that some economy will be effected in that way, and in due course the use of the method will spread to more difficult problems where it would be rash to make hurried changes. I quite appreciate the difference in outlook which must exist when testing goods which involve the safety of human beings, but I believe that there is a good deal of inspection which could be reduced by adopting the procedures I have described for the recording, and study of test data derived during manufacture.

SIR FRANK GILL, K.C.M.G. (*Chairman, Standard Telephones and Cables, Ltd.*): I am not a production man, my experience in this matter has been as a student. I have studied under Dr. Dudding and other people in other factories, and I have had an opportunity of discussing this matter very carefully with the Inspection Department of the Ministry of Aircraft Production, but I do not speak for them.

I have come to the conclusion that this thing is vital. It is vital because there is a war on; it is not something of which you can say "I cannot put it in while there is a war." It is something that we must put in because of the war. To the inspector it gives a very positive measuring tool. Usually we have an upper limit and a lower limit and we do not know what is happening in the middle; but this method is largely concerned with the exploration of what is happening in the middle. To the inspector it gives a knowledge of trends, of advancing troubles before they become troublesome. The limits Dr. Dudding has described are not set at contract tolerances but are finer than those so that you get information of tool wear, or other things, which warns you. You get such things as the spots which he showed coming out of proportion, which indicate an assignable cause, to use Shewhart's expression. It converts the inspector from an enemy of the production man to an assistant of the production man, which is worth while. It takes some of the trouble from the production man when

everything goes wrong, and he turns the place upside down to see what has happened. Here is a tool which will give him early warning and probably help him to find the trouble. You apply it to a process and not to a complete thing. To the buyer, who nowadays is the Government, it gives speedier production and less rejects. I imagine the A.I.D. would like to do what Brigadier Wood said, and say " If we are satisfied that the manufacturers are doing a first-class inspection job, we will leave it to them." Am I right ?

BRIGADIER WOODS : Yes.

SIR FRANK GILL : Now, imagine a Government inspector going into the works. He asks whether they keep control charts, and is told that they do, and he asks to see them. He can very quickly see what the control charts say ; he can see whether the product is under control, using " control " in the way that Dr. Dudding has used it. At that moment the only question is, is it true ? It may be a fake. He settles that point and, when he has done that, he can say, if there is good work, " Your manufacture is under control ; I am satisfied with what you are doing. What else are you doing that is not on a control chart ? " And then he can switch his attention to those things, because there may be things that the firm have not or cannot get under control. To the inspector, therefore, it means less work, and it means fewer inspectors and better work.

Now I come to the last point. I have learnt about this the value of the old Army slogan, " Learn while you earn." The best way to learn something about this system is to get going. Dr. Dudding has referred to an American book by L. E. Simon called *An Engineer's Manual of Statistical Methods.** That book contains the best " child's guide " to this system that I have come across. There are not many copies of it in this country, and I suggest that you should copy about four pages of an example which was put into force at an American Army ordnance factory at a place where there was no one who had more than what we should call a secondary school education. You must not take it as solving all the problems that arise, but it gives something on which to bite—something you can try, something from which you can learn. In the case in question they established their controls from the things actually going through after a few days' work. The advantage is that the man beginning to work with this thing handles it practically, and we all know how much quicker we learn when we begin to live with something.

MR. R. KIRCHNER (*Member, Arnott & Harrison, Ltd.*) : I think you will agree with me that while we have a very marked absence of lectures and meetings in the Institution we can say that this

*An extract from this book is published on page 55.

one meeting has at least made up in quality what we have lacked in quantity before. I do not propose to add to the technical comments which have been made—I am afraid I am not really qualified to do so. As the Chairman has said, probably some of us will know more about this subject in three or four days' time when we have had an opportunity to think about it. I will therefore ask you to join me in this pleasant task of passing a very cordial vote of thanks to Dr. Dudding and to his assistants, Mr. W. J. Jennett, Miss J. Keen, and Miss E. Barber, all members of the G.E.C. Research Staff.

The vote of thanks was carried by acclamation, and the proceedings then terminated.

(Communicated.)

Mr. H. Rissik : I should like to emphasize a point referred to only very briefly by Dr. Dudding, and which is often overlooked by those coming into contact with quality control for the first time. It is simply this : The application of statistical methods to the quality control of a manufactured product involves a technique of utter simplicity, no matter how abstruse or seemingly complicated may be the theory on which that technique is ultimately based. The quality control chart is, like the slide-rule, to be regarded as a scientific tool in the use of which the engineer can become, with a little practice, both confident and proficient. It was developed by an engineer, for engineers, and to fulfil specific engineering needs.

To illustrate the variety of such needs which this new engineering tool has been designed to meet, I will refer briefly to four instances of quality control technique with which I have been personally associated. The first concerns the development and production of a very special type of transformer for one of the Services. After the initial development troubles were overcome, production was at first carried out on what may be called a " jobbing shop " basis. The question then arose of setting specification limits for the various characteristics, *e.g.*, turns ratio, inductance, resistance, &c. Here quality control technique proved invaluable, firstly, in determining when the production had become stable and, secondly, in deciding what limits could be satisfactorily maintained in future production on a quality basis.

The second case relates to the controlling of the thickness of sheet rubber used in cable manufacture. The supplier had only recently set up a plant for producing the rubber sheet, and the variations in thickness proved to be excessive. It was necessary to produce evidence of this variability, with a view to analysis and eventual elimination of the causes at work. The records of several

months were analysed from the quality control standpoint, probability graph paper being extensively used as a labour-saving means of determining average values and standard deviations. Quality control charts were then set up and are now being successfully maintained.

The third example I have in mind is one where the manufacture of radio valves was being undertaken in a shadow factory. It was recently felt that the product was sufficiently stable to warrant the carrying out of inspection in the important pre-final stage on a sampling basis instead of on a 100 per cent basis, at any rate in the case of certain valve types. Past test records were, therefore, analysed and the statistical uniformity of the product was successfully established by the use of quality control methods. As a consequence the inspection has now been put on a sampling basis and the results are being recorded in the form of quality control charts.

All the foregoing instances refer to the quality control of products manufactured on a more or less continuous basis. I would mention, lastly, a somewhat different and much more difficult case of a factory engaged on vital precision engineering work where, about a year ago, the gradual dilution of labour began to tell on the general quality level throughout the Machine Shop. It was decided to introduce a scientific system of quality control and, to that end, certain changes in the inspection organisation and routine were made. The system was first introduced experimentally in one section of the Machine Shop. The benefits to be derived, although naturally not immediately apparent, soon became so evident that after a trial period of six months it was decided to introduce the system throughout the Machine Shop as a whole. It is perhaps a little too early to speak, in this particular case, of a finality of achievement as regards quality control. The number of different pieceparts involved is of the order of 12,000 with an average of some five machining operations on each. Obviously under these conditions there is continual scope for revision of methods in the light of experience. But there is no question that the experiment is proving a success, as evidenced by the steady decline in the rejection and rectification of pieceparts during recent months. (This particular case is discussed by Mr. R. Royan in his contribution to the discussion.)

MR. R. ROYAN (*Chief Inspector, Creed & Co., Ltd.*): I listened with very great interest to the lecture given on December 12th, 1941, by Dr. B. P. Dudding, under the auspices of The Institution of Production Engineers, on the subject of *Sampling Inspection and Quality Control*. Time taken by other speakers during the discussion following the lecture did not give me any opportunity of making a contribution at the meeting. As, however, the firm by

whom I am employed has been experimenting during the past fourteen months with the application of statistical science to the problems of quality control, I would like to state briefly our experiences in this direction with a view to assisting those who may be considering the subject for the first time.

The fundamental purpose of inspection in the manufacturing field is to intercept defective work at the earliest possible moment in the production cycle. It is as well that we should be clear on this vital point, because a very prevalent misconception on the subject of inspection is that the purpose of inspection is to sort out bad work from good *after* manufacturing time has been spent on the product. Without going more deeply into this point at the moment, it may be said that if the inspection department in any manufacturing concern has to spend the greater portion of its time in sorting out *completed* batches of components in order to determine which components are usable and which are not, and if components in the latter category represent a higher proportion than would normally be expected or desired, then such a condition indicates not only a lack of efficiency on the part of the producing elements in the manufacturing organisation but also that the efforts of the inspection department are ineffective and lacking in control of product quality during the course of actual production.

In the heavy engineering industries where the output is comparatively small and the use of skilled labour reduces possible defective work to a minimum, quality control is not such a problem. In the light engineering industries, however, engaged on the production of small, intricate components on a large batch basis, and where unskilled labour has to be employed to a very great extent in the Machine Shops, the problem of effective quality control is an acute one, and it may be that firms engaged in this class of work will find an effective solution to many of their difficulties by the application of more scientific methods in their inspection departments as based on statistical analysis of inspection findings leading to a more *positive* control of product quality.

In my own firm we manufacture something in the order of 12,000 different components, each component having an average of five separate and distinct manufacturing operations. Our problem has always been to keep the production of defective components to a satisfactory minimum, and to intercept errors in dimension and poorness of finish at a sufficiently early stage in production to avoid the delay in assembly and loss of material arising from the discovery of defective components after all the Machine Shop operations on them have been completed.

Our attention was drawn to the possibilities of more effective quality control by the application of statistically based methods during the latter part of 1940 ; and in November of that year we

experimented in one of our most troublesome Machine Shop sections by applying an inspection system having as its basis an inspection Record Card to cover the component under production on which the inspector would record the results of his findings when examining the product and which served as a guide to the inspector as to how frequently he should visit the machine producing the components, and how many components he should examine at each visit. The cards also indicated what the inspector should look for when examining the product.

We first applied these Record Cards to one or two troublesome components only, and with very satisfactory results. Scrap and otherwise defective work on these particular components was considerably reduced. These benefits arose from two immediate effects arising from the application of these record cards, *viz.*, the cards provided in themselves a *steadying influence* which affected not only the inspectorate but also the machine setters and operators engaged on producing the components; while the information filled in on the cards by the inspectors during the run of the batch, relative to the nature of the errors found in the components at the various inspection visits and the action taken to correct the errors, enabled us to see more clearly where the root of the trouble lay and gave indication as to what action was necessary with respect to tools and fixtures to bring about a more *positive* improvement in the quality of future batches of the same component.

Encouraged by that small beginning we have gradually extended the application of the system until, with the exception of the Punch Press Section, it now covers the whole of our Machine Shop production. The full extension of the system was effected by the end of April, 1941. Startling results were, perhaps, not immediate, and there have been occasions when we wondered if the application of the system—even in the simple form to which we had developed it—was worth while. As the months have passed, however, we have been able to record a steady general decline in the amount of defective work produced, to an extent which is encouraging us to proceed along the road to which we have set our feet, and which is inspiring us to develop the system on even more ambitious lines. During the three months from September to November inclusive of this year, for example, defective work from our Machine Shop has been reduced by about 50 per cent. This happy figure may not be taken as indicating a wholly *stable* state of affairs, as the amount of defective work is bound to fluctuate over a period of months. It is, however, indicative of a decided *downward* trend in our defective work curve, and this is what we want to see.

In conclusion, I want to make it clear that we are still in the *experimental* stage in so far as the application of statistical methods to our inspection work is concerned. At the moment we are mainly

concerned with the *compilation of data* on inspection findings. From this data we expect to be able to re-establish our inspection approach to our products in a manner that will make our inspectorate not only *more effective* but also *more economical* in the use of time and equipment. We still have a long way to go, and present-day labour conditions certainly do nothing to lessen our difficulties; but we feel encouraged to go ahead by the results so far obtained, and it may be that other firms engaged on a similar type of product would derive similar benefits if they, too, examined their inspection departments with the object of discovering where a more scientific approach to the establishment of an inspection routine would result in greater general inspection effectiveness.

Note.—The above communications support the main thesis of Dr. Dudding's paper. Mr. Royan's experience shows (a) *that statistical methods are of value in the field of engineering inspection,* (b) *that waste is reduced,* (c) *that once introduced, even in a simple manner, the use is soon extended, and* (d) *that real appreciation of the simplicity and power of the methods only comes from personal experience.*

APPENDIX TO DR. DUDDING'S PAPER: ILLUSTRATION OF A SIMPLE QUALITY CONTROL SYSTEM*

Instructions for Control of Quality of Product thru Percentage Inspection.

GENERAL INSTRUCTIONS.

1. The following procedure is designed to govern the inspection of all manufactured items on which the nature of the work performed can be measured quantitatively, *e.g.*, weight of explosive charge in various components, explosive power of detonators in terms of weight of sand crushed, specific gravity of cast or pressed materials, burning time of fuses, &c., except where 100 per cent inspection is performed.

Sampling Schemes.

2. The sampling scheme described herein is based on a sample of five items per hour, and is practical on the majority of production orders. In some instances, however, the cost of sampling may prohibit this procedure; whereas, in others, more extensive sampling may be advisable, especially at the beginning of an order. Hence, the shop inspector will submit his recommended sampling scheme to the Department Chief for approval prior to production. The procedure for other sampling schemes is covered in notes on sampling schemes.

DUTIES OF THE FOREMAN.

Sampling.

3. Take a sample of five items from the assembly line each hour, day or other period of time, as instructed by the shop inspector.

Recording Observations.

4. Accurately measure each sample with regard to size, weight, explosive power, or other characteristic described by the respective drawing and specification and record the measurements in the order taken.

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*Taken from Appendix " C " of *An Engineer's Manual of Statistical Methods*, by Leslie E. Simon. Published by John Wiley & Sons, Inc., New York; and Chapman & Hall, Ltd., London, 1941. Reproduced by special permission of the publishers.

Computing Data.

5. (*a*) Take the sum of the five recorded measurements of the group and divide it by 5. This figure is known as the "average" or "mean," and is designated by the symbol $\bar{X}$ (bar X).

(*b*) For each group of five, subtract the smallest recorded measurement from the largest recorded measurement. This figure is a measure of dispersion and is commonly known as "range" or "maximum dispersion," and is designated by the symbol W_t (W sub t).

(*c*) Table I shows a sample of Foreman's Data.

FROM TABLE I.

First five Recorded Measurements ...	39·0 38·0 36·5 37·6 38·9	First "range" or "Maximum Dispersion" (W_t)...	39·0 36·5
	5)190·0		2·5
Average ($\bar{X}$) .... =	38·0		

First average	38·0	First range	2·5
Second "	38·4	Second "	2·0
Third "	37·9	Third "	2·0
Fourth "	37·9	Fourth "	2·3
Fifth "	38·6	Fifth "	2·1
Sixth "	38·3	Sixth "	1·9
Seventh "	38·1	Seventh "	2·3
Eighth "	38·0	Eighth "	2·1
Average of eight averages = (or $\bar{\bar{X}}$)	38·15	Average of eight ranges = (or $\bar{W}_t$)	2·15

See paragraph 10*a*.	Average of eight averages	$\bar{\bar{X}}$
" 10*b*.	" eight average ranges...	$2{\cdot}15 = \bar{W}_t$
" 10*c*.	$\bar{W}_t \times 0{\cdot}594 = 1{\cdot}28$..............	$= \pm$ control on Average Chart.
" 10*d*.	$\bar{W}_t \times 2{\cdot}08 = 4{\cdot}47$	Upper control on Range Chart.
	$\bar{W}_t \times 0{\cdot}254 = 0{\cdot}55$..............	Lower control on Range Chart.

Plotting Data.

6. (*a*) Plot the chart described in Fig. 1 on cross section paper. Head the chart "Control Chart for....................," (inserting the name of the item sampled), "Samples of five" followed by the production order number. On the face of the chart indicate the lot number or batch from which the samples were taken, the approximate daily production, and the designated measurement that the items should meet, *e.g.*, weight of charge 38·0 gr. ± 3·0 gr., per drawing 76–4–32, revised 7–2–33.

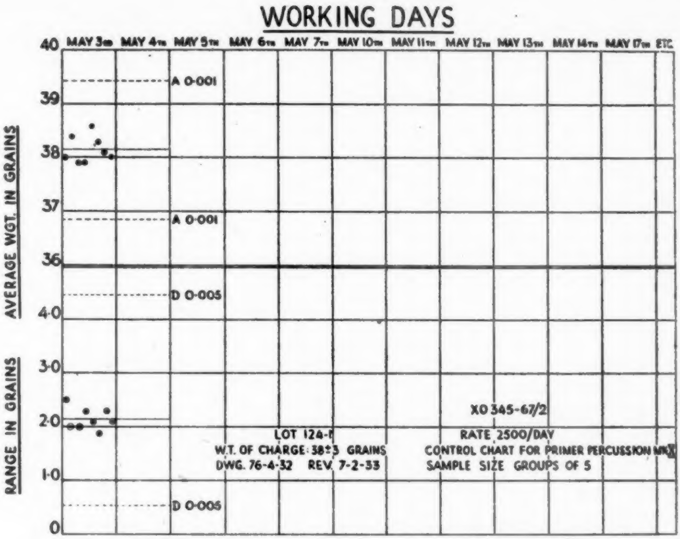

FIG: 1 CONTROL CHART AT END OF FIRST DAY

POINTS : BY FOREMAN
LIMITS : BY SHOP INSPECTOR

(*b*) On the pieces of cross section paper mark a horizontal scale across the top for the working days of the month, *e.g.*, May 3rd, May 4th, &c. Ordinarily, one linear inch for each day is convenient. If the paper has eight divisions to the inch, one division will represent a working hour of the working day.*

(*c*) Mark two vertical scales on the left-hand margin of the paper—one near the top for the purpose of recording the averages ($\bar{X}$'s), and one a moderate space below it for recording the ranges (W_t's).

(*d*) Plot the observed average ($\bar{X}$) for each group of five (see paragraph 5. (*a*) above) opposite the vertical scale for averages (see paragraph 6. (*c*) above), and under the horizontal scale for date and hour (see paragraph 6. (*b*) above).

(*e*) In like manner plot the observed range (W_t) (see paragraph 5. (*b*) above) opposite the vertical scale for range and under the appropriate date and hour. Data should be plotted as promptly as practicable, and at least prior to the observation of the next group of data.

*Editorial Note.—Evidently a pre-war working day.

Foreman's Interpretation of the Chart.

7. Limits will be placed on the chart by the Shop Inspector within which practically all poin s should fall (see paragraphs 10 and 13 below). If any points fall outside of these limits call the Shop Inspector without delay.

Disposition of Charts.

8. The Foreman will conspicuously post the chart in the nearest office to the place of work while the work is in progress and, upon the completion of the production order, will forward the chart to the Department Office for file, *as a record of the quality of the product.*

Delegation of Duties.

9. In lieu of personally performing the functions outlined in paragraphs 1 to 8 inclusive, the Foreman may designate one or more trusted assistants to do them under his supervision. Such assistant may not in any case be the workman who performs the work being sampled.

DUTIES OF THE SHOP INSPECTOR.

Computing and Plotting Control Limits.

10. (*a*) After the data from between eight and eighty groups of five has been plotted (see paragraph 11 below), compute the average of the observed averages. This figure is designated as $\bar{\bar{X}}$ (bar bar X). Draw a heavy horizontal line on the chart for averages at the computed figure and under the hours for which the samples were taken.

(*b*) Compute the average of the eight to eighty observed ranges. This figure is called $\overline{W}_t$ (bar W sub t). Draw a heavy horizontal line on the chart for ranges at this value and under the hours for which the samples were taken.

(*c*) Multiply $\overline{W}_t$ by 0·594 and plot two heavy dotted lines on the chart for averages parallel to the heavy line at $\bar{\bar{X}}$ and located at $\bar{\bar{X}} \pm 0{\cdot}594\ \overline{W}_t$. Mark each of the lines A 0·001.

(*d*) In like manner, plot two heavy dotted lines on the chart for ranges, one at $2{\cdot}08\ \overline{W}_t$ and one at $0{\cdot}254\ \overline{W}_t$. Mark each of these lines D 0·005.

Judging and Interpreting of Charts.

11. (*a*) Practically no plotted values of $\overline{X}$ should fall outside the dotted limits A 0·001 (theoretically only one above and one below in a thousand). Hence, the presence of a point outside the dotted limits is a very strong indication that the general level of quality (weight of material in a component, size, strength, or other quality) is changing from time to time. The Shop Inspector will advise the foreman to investigate at once to determine if someone

is doing something wrong, if some machine is functioning wrong, if a change has been made in the raw material, &c., and the Shop Inspector will also report the situation to the Department Chief without delay.

(*b*) A significant deviation of $\bar{\bar{X}}$ from the mean value designated by the drawing or specification obviously calls for measures to bring the average of the product in closer alignment with the designated average, and the Shop Inspector will advise the Foreman accordingly. The X from 80 groups of 5 is generally so near the true value of the product sampled that for purposes of control is may be treated as such.

(*c*) Practically no plotted values of W_t should fall outside the dotted limits D 0·005 (theoretically only 5 above and 5 below in a thousand). The presence of a point outside these limits is a strong indication that the variation in the product (lack of uniformity) is greater than it should be. The same action will be taken as outlined in (*a*) above.

(*d*) With respect to both charts, the plotted dots should be scattered rather evenly on both sides of the central line; the greater portion should be near the central line, and only relatively few should fall near the dotted limits. Trouble can frequently be forestalled by a study of the charts. If there is a general drift of the plotted points on either chart toward the bottom limit or the top limit, a timely investigation may eliminate the cause of the drift and prevent the occurrence of a point outside the limits. In like manner the too frequent occurrence of points at a value other than in the immediate vicinity of the central value indicates erroneous observations probably due to a faulty measuring instrument, use of an instrument not sufficiently sensitive for the work involved, or bias on the part of the observer. Action same as outlined in (*a*) above.

Number of Groups on which Limits should be based.

12. In the interest of accuracy, convenience, and economy of labour, it is desirable to have limits plotted on the data from 80 groups of five (a normal 10 working-day period). However, at the beginning of a job, limits should be calculated on the first eight plotted points; then after a total of 16 have been accumulated, then after a total of 40, and finally after 80, all preceding points included in each successive calculation. The next set of limits will be based on the next 80 points, *viz.*, points No. 81 to No. 160 inclusive, &c.

Predicting Limits.

13. The importance of these charts lies not so much in disclosing that trouble occurred yesterday, or last week as in *disclosing it*

instantly, or before it occurs. Hence, it is most important that limits exist for the plotted points (see paragraph 7), *before the points are plotted*. To accomplish this purpose, the Shop Inspector will, at the time he computes and plots a set of limits for a period of eight to 80 plotted points, extend these limits in light lines for the next date period. These extended limits are binding upon production for the next period during which another set of plo ted points are being accumulated (see paragraph 7). The limits fr m the accumulated ata will then se ve a a check on these extended limits and as a basis for new extended limits. Thus, when limits are calculated as detailed in paragraph 10 and extended as detailed in this paragraph, there are always limits predicted ahead, except for the first eight points. Even this deficiency can be supplied by taking advantage of data from a previous order, and this procedure should be followed if such data are available.

Meeting Drawings and Specifications.

14. The meeting of drawings and specifications (as most of them are now written) is often more a matter of engine ring, judgment, and interpretation than of mathematical statistics. In general, the drawing or specification will state that the product (presumably meaning every i em thereof) wil be $A \pm (d)$. Actually, there is no way of knowing if every item falls within the limits $A \pm (d)$ unless every item is sampled and, if the sampling be destructive, there is no product left. However, if the product has showed "control" during manufacture; *i.e.*, practically no points have fallen outside the control limits; no exhibition of a pronounced drift or trend; and, if the number of plotted points be large (*e.g.*, 40 or more) then it can be said with reasonable certainty that approximately 90 per cent of the individual items will lie between $\bar{\bar{X}} \pm 0{\cdot}707\,\bar{W}_t$; 95 per cent between $\bar{\bar{X}} \pm 0{\cdot}843\,\bar{W}_t$; and $99\frac{1}{2}$ per cent between $\bar{\bar{X}} \pm 1{\cdot}21\,\bar{W}_t$. (For $\bar{\bar{X}}$ and $\bar{W}_t$ see paragraphs 10. (*a*) and 10. (*b*) respectively.) Upon completing each period of 80 points the Shop Inspector will note on the chart "approximately $99\frac{1}{2}$ per cent within $\bar{\bar{X}} \pm 1{\cdot}21\,\bar{W}_t$," substituting for $\bar{\bar{X}}$ its numerical value and for $1{\cdot}21\,\bar{W}_t$ its numerical value.

NOTES ON SAMPLING SCHEMES.

Time not a Factor.

15. It is not necessary that the groups of five be taken each hour. All the rules outlined above apply with equal force if the groups of five be taken every half hour, every five minutes, day, week, or other period of time, just so long as the observations are grouped in fives. Hence, in devising sampling schemes, sampling may be increased or decreased at will by merely varying the time interval.

Grouping.

16. Groups of four can be used just as readily as groups of five by changing all 5's to 4's and changing constants as follows :—

Paragraph 5. (*a*) ... Divide by 4 instead of 5.
Paragraph 10. (*c*) ... Change 0·594 to 0·750.
Paragraph 10. (*d*) ... Change 2·08 to 2·26 ; and 0·254 to 0·185.
Paragraph 14. ... Change 0·707 to 0·798 ; 0·843 to 0·952 ; and 1·21 to 1·36.

Groups of 10 can be used instead of groups of five by changing all 5's to 10's and changing constants as follows :—

Paragraph 5. (*a*) ... Divide by 10 instead of 5.
Paragraph 10. (*c*) ... Change 0·594 to 0·318.
Paragraph 10. (*d*) ... Change 2·08 to 1·755 and 0·254 to 0·439.
Paragraph 14. ... Change 0·707 to 0·536 ; 0·843 to 0·637 ; and 1·21 to 0·913.

For a given number of observations, the relative precision of results obtained by the use of groups of 4, 5, or 10 under the method outlined is practically the same. However, the smaller groups are to be preferred because of their greater sensitivity to a changing cause system, which is of relatively great importance in manufacture.

The following change is added to *Instructions for Control of Quality of Product thru Percentage Inspection.*

Interpolate in paragraph 16.

Groups of six can be used just as readily as groups of five by changing all 5's to 6's, and changing constants as follows :—

Paragraph 5. (*a*) ... Divide by 6 instead of 5.
Paragraph 10. (*c*) ... Change 0·594 to 0·498.
Paragraph 10. (*d*) ... Change 2·08 to 1·97, and 0·254 to 0·308.
Paragraph 14. ... Change 0·707 to 0·649 ; 0·843 to 0·773 ; and 1·21 to 1·11.

17. Although groups of four, five, six, or ten are to be preferred, groups of two or three can be used.

Groups of two can be used instead of groups of five by changing all 5's to 2's, and changing constants as follows :—

Paragraph 5. (*a*) ... Divide by 2 instead of 5.
Paragraph 10. (*c*) ... Change 0·594 to 1·94.
Paragraph 10. (*d*) ... Change 2·08 to 3·52, and 0·254 to 0.
Paragraph 14. ... Change 0·707 to 1·46 ; 0·843 to 1·74 ; and 1·21 to 2·49.

Groups of three can be used instead of groups of five by changing all 5's to 3's and changing constants as follows :—

Paragraph 5. (*a*) ... Divide by 3 instead of 5.
Paragraph 10. (*c*) ... Change 0·594 to 1·05.
Paragraph 10. (*d*) ... Change 2·08 to 2·58, and 0·254 to 0·10.
Paragraph 14. ... Change 0·707 to 0·972 ; 0·843 to 1·16 ; and 1·21 to 1·66.

18. In some cases where averages ($\overline{X}$'s) are plotted, it becomes necessary to obtain the limits for the chart for averages from the chart itself, instead of from the average range W_t. This procedure can be accomplished as follows: ignore the chart for ranges, if one exists. Consider the first five plotted averages as observations. Subtract the least from the greatest. Call this value $W_{t_{\overline{X}}}$ (W sub t bar X).

Consider the next five plotted averages as observations; subtract the least from the greatest, thereby obtaining another $\overline{W}_{t_{\overline{X}}}$, &c. Upon the completion of this process for all available plotted averages, compute the average of the $\overline{W}_{t_{\overline{X}}}$'s. Call this value $\overline{W}_{t_{\overline{X}}}$. The average of the averages $\pm 1{\cdot}33\,\overline{\overline{W}}_{t_{\overline{X}}}$ will give the A 0·001 limits for the chart for averages. This method should only be used when there is no chart for ranges or upon the advice of the Department Chief.

LESLIE E. SIMON,
Captn., Ord. Dept.

Lecturer's Comments on the Appendix.

If full advantage is to be taken of the Appendix following the main paper the notation should be brought into line with British practice—

thus for $\overline{X}$ read $\overline{x}$
and ,, $\overline{\overline{X}}$,, $\overline{X}$.

Further, much of the value of the method is lost if only limits are used outside which results provide "*a very strong indication* of a change" (*e.g.*, see "Duties of Shop Inspector," sections 10 and 11). Inner limits which constitute a warning should also be incorporated.

Thus in this case (samples of five) (*a*) in addition to:—

"A 0·001 limits at $\overline{\overline{X}} \pm 0{\cdot}594\,\overline{W}_t$"

introduce also:—

A 0·025 ,, ,, $\overline{\overline{X}} \pm 0{\cdot}376\,\overline{W}_t$

and (*b*) in addition to:—

"D 0·005 limits at $2{\cdot}08\,\overline{W}_t$ and $0{\cdot}254\,\overline{W}_t$"

introduce also:—

D 0·05 ,, ,, $1{\cdot}83\,\overline{W}_t$ and $0{\cdot}48\,\overline{W}_t$

Similar considerations can be applied to the limits for samples of 2, 3, 4, 6, and 10.

Research Department: Production Engineering Abstracts

(Edited by the Director of Research)

NOTE.—*The addresses of the publications referred to in these abstracts may be obtained on application to the Research Department, Loughborough College, Loughborough.*

ANNEALING, QUENCHING, CASE-HARDENING.

Annealing Nickel, Monel, and Inconel, International Nickel Co., Inc. (*Tech. Bull., T. 20, 1941, p. 14.*)

The publication gives very comprehensive details of recommended practice for annealing, combined with particulars of apparatus required for treatment. The properties of the materials are tabulated and discussed in relation to selection of optimum annealing conditions.

(*Communicated by "The Nickel Bulletin."*)

Heat Input and Hardness, by J. G. Magrath. (*The Machinist, December 27, 1941, Vol. 85, No. 40, p. 915, 6 figs.*)

A remarkable thing about flame hardening is its ability to give the desired depth of hardness where it is needed. It is done by controlling heat application. The depth of hardness obtainable can be varied within reasonable limits and may be as uniform as desired. It will vary, plus or minus, depending upon such factors as distance of flames from the work, severity and position of the quench, the thickness and shape of the part heated, and the metal analysis. Depths of hardness on steels or cast irons, under precise control, may range from a superficial hardness of a few thousandths of an inch in some cases to ¼in. or more. The minimum depth required should always be provided. The deeper the hardened layer the greater the hardening stresses, which, when sufficiently high, will tend to produce distortion.

ADMINISTRATION, ACCOUNTING.

Planning for the Small Undertaking, by E. C. Halford. (*The Factory Manager, December, 1941, Vol. IX, No. 12, p. 638.*)

There are three main requirements: (1) a planning system; (2) a time-keeping system; (3) a costing system. Example with fictitious figures and amounts.

Deterioration and Loss in Fixed Assets and Its Recovery, by E. V. Amsdon. (*The Cost Accountant, December, 1941, Vol. 21, No. 6, p. 241.*)

A considerable proportion of the assets used in industry are subject to some deterioration or diminution in value. The magnitude of these losses tends to increase, which makes it more necessary than ever that they should be promptly recovered. Main classes of fixed assets. Nature of losses. Wear and tear. Depreciation. Obsolescence. Measurement of the loss. Length of life. Scrap value: (1) diminishing value method; (2) straight line method; (3) the sinking fund method; (4) annuity method; (5) other methods. Investment of sums written off. The choice of a method: Abnormal losses. Inland revenue tax methods. United States tax methods. Methods in this country. Inadequate

inland revenue allowances. Tools, &c. How to obtain increased income tax allowances for wear and tear. Government contracts. Excess profits tax and depreciation. Conclusions.

BELTS AND ROPES.

The Vulcanised Belt Joint, by H. Stuart Jude. (*Power Transmission, December, 1941, Vol. 10, No. 119, p. 496, 2 figs.*)

The "difficulties" sometimes experienced in making a satisfactory splice in rubber belting disappear when simple rules are obeyed. The necessary tools. Cutting to length. Stepping down the plies. Making the joint.

COOLANT, LUBRICANT.

A Study of Cutting Oils With and Without Added Sulphur, by O. W. Boston and J. C. Zimmer. (*Amer. Soc. for Metals, Preprint 8, October, 1941, p. 16.*)

The paper gives results of a study of the effects on machining performance of oils with and without added sulphur. The experimental work recorded was carried out on a nickel-chromium steel (S.A.E.3140: carbon 0·35–0·45%, nickel 1·0–1·5%, chromium 0·45–0·75%), and on various grades of carbon steel.

(*Communicated by "The Nickel Bulletin."*)

The Flexible-Sleeve Multiple-Oil-Film Radial Bearing, by Gustave Fast. (*Transactions of the A.S.M.E., U.S.A., November, 1941, Vol. 63, No. 8, p. 725, 6 figs.*)

The flexing of the continuous block-sleeve-bearing member under load provides a multiplicity of wedge-shaped oil-film boundaries which create shearing stresses in the circulating oil and produce useful load-carrying pressures in the oil films. Careful tests have been conducted on the multiple-oil-film radial bearing under different conditions of speed, load, and oil viscosity, in order to determine its operating characteristics. These test data are summarised and discussed.

EMPLOYEES, WORKMEN, APPRENTICES.

Salary Evaluation, by A. S. Knowles. (*Personnel, U.S.A., November, 1941, Vol. 18, No. 3, p. 134, 9 figs.*)

While the past decade has been prolific of literature on salary determination, many of the articles published have been limited in scope or esoteric in content. Here then, for the company desiring a practical approach, is an over-all treatment of a survey of salary evaluation as practiced by 45 concerns which have definite plans in use. With this array of data the authors proceed to outline a workmanlike system for appraising salaried jobs.

Trends in Adjustments in Salaries, by H. B. Burgen. (*Personnel, U.S.A., November, 1941, Vol. 18, No. 3, p. 118.*)

With wages of factory workers rising on a broad front, progressive companies have begun to devote considerable attention to the problem of adjusting the "white collar" worker's compensation to increases in the cost of living. In making such adjustments, however, methods must be devised which will preserve flexibility in the salary schedules, and management must avoid making commitments which will extend into the post-war deflationary period. An eight-step programme is outlined for adjusting "white-collar" pay which meets these specifications.

American Industrial Relations Digests. (*Labour Management, December, 1941, Vol. XXIII, No. 255, p. 172.*)

No. 1: The organisation of a Personnel Department. A—Relation of a Personnel Department to the operating organisation. B—Division of

duties within the department. C—Chart I: Industrial relations department in company with approximately 5,000 employees; Chart II: Functional organisation of the Personnel Department in company with 18,000 employees. D—Committees.

HEATING AND VENTILATION.

The Purification of Air and Gases. (*Machinery, December 11, 1941, Vol. 59, No. 1522, 2 figs., p. 298.*)

The elimination of dust, fumes, smoke, fog, and mist from the atmosphere, the separation and collection of particles of solids and liquids in suspension in air and gas, are problems of paramount importance in modern life not only because of the influence of atmospheric impurities on the health of people living in industrial centres, but also because of the loss of dispersion into the atmosphere of valuable material which cannot be recovered. A large blast-furnace, for instance, discharges over 2,000lb. of dust into the atmosphere every hour. Dry filters, wet filters, and the Traughber Froth flotation filter are described in the article.

JIGS AND FIXTURES.

Universal V-Blocks for Tool Work, by J. G. Derck. (*Machinist, December 27, 1941, Vol. 85, No. 40, p. 910, 13 figs.*)

A dividing head, a circular drilling fixture, and several universal drill jig set-ups can easily be made up from this set of V-blocks and attachments, as can many other time-saving set-ups for tool and die work. These blocks and attachments may be used for many jobs that otherwise would require specially made jigs or more expensive equipment.

Work-Clamping Devices—III, by J. G. Jergens. (*The Machinist, December 13, 1941, Vol. 85, No. 38, p. 852, 19 figs.*)

Nineteen examples of various clamping devices are shown. A number of these devices can be assembled from standard parts which are interchangeable with other clamping arrangements.

A Semi-Automatic Gear Box, (*Automobile Engineer, December, 1941, Vol. XXXI, No. 418, p. 443, 5 figs.*)

The main units of this automatic gear are a fluid flywheel and three sets of epicyclic gearing controlled by band brakes and multiplate clutches. The whole of the control is effected by hydraulic operated pumps, a speed governor, and two servo mechanisms. There is also an over-riding hand control enabling the driver to choose between a high range and a low range of gearing, in addition, of course, to the neutral and reverse positions.

MACHINE ELEMENTS.

Composite Engine Bearing. (*American Aviation, U.S.A., Vol. 5, No. 10, 15/10/41, p. 43.*)

A patent on a composite engine bearing has been granted to United Aircraft Corporation, East Hartford, Conn., maker of Pratt & Whitney aircraft engines. The bearing comprises a steel shell which is internally lined with silver; the surface of the silver is roughened and has a layer of lead deposited on it electrolytically. The lead coating, which is only about 0·006in. thick, may be finished by rolling.

(*Communicated by D.S.R., Ministry of Aircraft Production.*)

Ball and Roller Bearings and Lubrication, by H. West. (*Power Transmission, December 15, 1941, Vol. 10, No. 119, p. 473, 26 figs.*)

Increasing utilisation of ball and roller bearings during the last thirty years. Single row, deep groove ball bearing. Single row, cylindrical


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roller bearing. Ball thrust washer bearing. Ball bearing assemblies for a small motor. Left-hand side free, right-hand side fixed. (*a*) Double row self-aligning bearing; (*b*) single row self-aligning bearing. Conditions arising under end thrust when the outer race of a ball bearing is not free to slide. Apparatus for checking alignment between inner and outer cages on a ball and roller bearing. Mounting and assembly. Lubrication. Bearing troubles. Stationary vibration—"Brinelling." Dismantling damage. Deficient lubrication. Overloading. Etching or staining.

MACHINING, MACHINE TOOLS.

Electro-mechanical Control for Medium-sized Machine Tools, by F. Koenigsberger. (*Machinery, December 25, 1941, Vol. 59, No. 1524, p. 349, 12 figs.*)

One of the most important problems for the designer is that of the controls, which have to be as universal as possible and, at the same time, simple and reliable. These latter qualities are required to ensure that not only may semi-skilled men operate the machines, but that they may exploit the capacity of the machine to the full. One great advantage of mechanical controls must, however, be realised. These controls are generally positive, so that they only fail if one of their members breaks, and this under normal conditions is not very probable. Hydraulic controls have been applied mainly in combination with hydraulic drives, first on presses, and later on planers, grinders, lathes, broaching and milling machines. They can be simple in many cases, but may become complicated when they have to be connected with moving saddles, &c. With the abolition of the belt drive from the line-shafts and the introduction of self-contained motors the possibility of the electrical control of machine tools became evident. The greatest weakness of electrical control is the fact that the contacts are subject to wear, and that a worn contact, a piece of dirt between two contacts, or a loosened connection may jeopardise the functioning of the control. It is important to realise that the advantages of electrical controls can be amplified by combining them with certain mechanical arrangements.

Hints for Lathe Operators—I and II, by Albert Huff. (*The Machinist, December 20, 1941, Vol. 85, No. 39, p. 887, 9 figs.*)

A series of 25 hints dealing with set-up operations, turning operations, threading operations, reaming, and boring.

A Multiple Drilling Head with Traverse and Indexing. (*Machinery, December 25, 1941, Vol. 59, No. 1524, p. 367, 4 figs.*)

This article shows how four Desoutter pneumatic drills were combined to form a multiple drilling head, thus eliminating special jigs and machines, and the possibility of cumulative error which would have arisen if the indexing principle were used.

An Analysis of the Milling Process, by M. E. Martellotti. (*Transactions of the A.S.M.E., U.S.A., November, 1941, Vol. 63, No. 8, p. 677, 45 figs.*)

The path of a milling-cutter tooth is an arc of a trochoid, the parametric equation for which can be derived from known variables of the cut. As a result the milling process is susceptible to mathematical treatment. Practically, the advantage of such analytical methods is that such elements as the radius of curvature of the tooth path, the clearance and rake angles of the length of the tooth path, the radial thickness of the chip, and their effects upon the quality of milled surface may be evaluated. The advantages of the up-milling process in achieving machined surfaces of high quality.

CHIPLESS MACHINING.

Operations with Rubber Dies, (*Machinery, December 4, 1941, Vol. 59, No. 1521, p. 253, 8 figs.*)

Presses developed by the Machine Tool Directorate of the Ministry of Aircraft Production are larger and capable of exerting greater total pressures than hitherto. These presses have been designed in all respects with a view to economical production, and are proving very satisfactory in use. The degree of hardness of the rubber used is decided by the depth of the pressing. When flanging, forming stiffening ribs, or beading, say, the edge of lightening holes, a Shore hardness of 75 is suitable, whereas if deep drawings are to be done a softer type of rubber is used. The large solid dies weighing from two to three tons require a very strong form of suspension. A very satisfactory method is to secure a perforated and counterbored steel backing plate to the rubber. Rubber, when in its plastic state, is forced into the holes under pressure and vulcanizes. In this way the rubber is locked to the plate. A coarse working rubber surface is an advantage as it prevents adhesion between the rubber and the work. A piece of thin rope roughly zig-zagged over the surface of the plate will also effectively serve this purpose. Should the working surface of the rubber become badly damaged locally, this can be repaired in situ. Temporary dies made of seasoned hardwood are suitable when only a few hundred of these are required. If faced with metal to serve as protection, then several thousand items can be produced. Composite materials made of fine wood chips, cemented into a solid mass with a suitable binding material and finally compressed into sheets, are used to form laminated blocks. More permanent dies can be cut from $\frac{3}{4}$in. thick zinc sheet spindled to shape. Using steel shearing dies, sheets up to 18 gauge can be blanked without a trace of burr on the sheared edges, and holes can be pierced successfully down to $\frac{1}{2}$in. diameter. Shearing dies are normally from $\frac{1}{4}$in. to $\frac{1}{2}$in. thick and made of steel plate. As an example of blanking, a fuselage frame can be sheared from a 4ft. by 4ft. sheet of 17 gauge Dural. The pressure required to do this is about 4,500 tons. Sheet steel of 36 tons tensile has been sheared successfully up to 16 gauge thick with simple steel dies and rubber pads.

These presses are very massive structures, each individual unit weighing approximately 85 tons. A 4-unit press will weigh 340 tons, and gives a pressure of 1·54 tons per square inch over an area of 36 square feet.

MANUFACTURING METHODS.

War Production with New Machines, by F. Dull. (*The Tool Engineer, U.S.A., November, 1941, Vol. X, No. 11, p. 52, 1 fig.*)

Because of greater efficiency and faster production every possible new machine tool that we can build must be put into operation for production of the materials of modern warfare. Three times as productive. Effective tooling. High accuracy up to interchangeability by unskilled labour.

War Production with New Machines, by Arnold Thompson. (*The Tool Engineer, U.S.A., November, 1941, Vol. X, No. 11, p. 49, 2 figs.*)

By adapting old machine tools for precision production, rather than marking time while waiting for new machines, democracy can speed the job of producing the materials of war.

Machining Large Radii, by W. F. Walker. (*Machine Shop Magazine, December, 1941, Vol. 2, No. 12, p. 62, 5 figs.*)

Preliminary machining. Example: Arcuate forging of 4ft. 6in. radius to be jig bored and ground on the edges. Grinding fixture. Setting and checking gauge. Setting up for grinding. Gauge for setting and checking. The grinder carried on the arm.

Machining the Rolls-Royce Engine, by J. A. Ashburn. *(The Tool Engineer, U.S.A., October, 1941, Vol. X, No. 10, p. 47, 12 figs.)*

In 40 weeks Packard has built and set in operation a plan to build Rolls-Royce aircraft engines, which represents a new peak in the application of automotive mass-production methods to aircraft.

The Blackburn Botha, by Wilfred E. Goff. *(Aircraft Production, January, 1942, Vol. IV, No. 39, p. 129, 24 figs.)*

Part III.—Building the fuselage; forward, rear, and centre sections; final assembly.

The Working of Nitriding Steels. *(The Machinist, December 20, 1941, Vol. 85, No. 39, p. 875, 6 figs.)*

Certain steels can be case-hardened at low temperatures, and without final quenching, by the action of a nitrogenous medium such as ammonia gas. The nitrides impart extreme hardness to the surface of the steel. Because the nitrided case is obtained at low temperature, the high surface hardness is produced with minimum warpage and distortion of the treated articles. Great wear resistance, retention of hardness at elevated temperatures, and resistance to certain types of corrosion are other properties imparted to the steel by nitriding. Certain alloying elements, such as aluminium, chromium, molybdenum, and vanadium, when used in various combinations, have great affinity for nitrogen; therefore, alloy steels particularly suited for nitriding have been developed. These steels are known commercially as nitralloy. The article deals with alloying elements, including nickel, chromium, molybdenum, also preparation for nitriding. Welding, equipment for nitriding, and nitriding procedure. Reference is also made to operations after nitriding, including correction methods, hardness testing, denitriding. Service properties are also mentioned. Finally, machining and nitriding steels are dealt with, including drilling, broaching, tapping and threading, milling, sawing, and grinding. The problems of cutting angles, feed, speed, depth, choice of cutting oils, choice of grinding wheels, &c., are treated in considerable detail.

The Machining of Copper and its Alloys (book review). *(Issued by the Copper Development Association, Thames House, Millbank, London, S.W.1. C.D.A. Publication No. 34.)*

The book (107 pages, 43 figs., 20 data tables) discusses the machining properties of copper alloys, and summarises modern machining practice as applied to these materials. Contents: Classification of copper alloys; general machining practice: tool design, rigidity, cutting tool materials; speeds and feeds; cutting fluids; machining operations: turning, shaping and planing, facing, parting and forming, automatics, knurling and thread rolling, porous bearings; drilling: boring, reaming, screwing, tapping; milling: sawing, broaching, grinding. Selection of copper alloys for machining purposes; cutting speed table; weight of rod; decimal equivalents of an inch; stress conversion table.

Stretch Pressing. *(Aircraft Production, January, 1942, Vol. IV, No. 39, p. 121, 12 figs.)*

Principles and applications; economies in tooling; production of large skin sections. The need for cheap tooling in airframe production, particularly in regard to the forming of sheet-metal parts, has had a marked effect upon manufacturing methods generally. A typically hydraulically-operated stretching press of modern design. Diagrammatic arrangement of a stretching press, showing the operating principle. Stretching magnesium-alloy sheet. Various types of built-up wooden forming tools as used by the Junkers Company. Transverse forming. A die shaped

to return curve to assist transverse forming. Forming Spitfire leading-edge skin sections on a twin 300-ton Erco stretching press. Stretching large skin sections. Counter-pressure forming. Forming troughs in cowling panels on a stretching press fitted with an hydraulically-operated counter-pressure die. Diagrammatic arrangement of a stretching press with a rotatable table, developed by the Henschel Aircraft Company, of Germany.

The Manufacture of Articles from Powdered Metals, by W. D. Jones. (*Engineering, December 26, 1941, Vol. 152, No. 3963, p. 515.*)

Most engineers and metallurgists, and probably a good many technicians concerned with plastics, appear to find it difficult to believe that articles and masses having good physical properties can be made by moulding metal powders, and that the art shows every sign of rivalling the plastics industry in magnitude during the next decade. The possibilities of the technique and the phenomena involved are more easily appreciated if two things are borne in mind: first, that, very broadly, the technique follows that of the plastics industry; and, secondly, that the principal phenomenon involved in moulding metal powders is that of simple welding. One of the most important advantages possessed by the powder metallurgy technique is that articles can be made exactly to size and shape without machining. During the sintering stage dimensional changes occur which may be either a growth or a shrinkage, generally the former, and one of the difficulties in manufacture is the close control of these changes. The familiar hard-metal carbide materials for cutting tools known as Widia, Ardoloy, Cutanit, &c., are manufactured from powdered products, and the modern contact material is another fine example of the application of powder metallurgy. The Alnico magnet is also a very fine example of the modern powder metallurgy technique. Further examples of circumstances in which it is more convenient or better to use the powder metallurgy technique than casting are afforded by the refractory metals, such as tungsten, molybdenum, tantalum, platinum, &c. All these materials can be cast, but it is an expensive and difficult process in view of the high melting points, and, in many cases, the cast product is not so satisfactory as that made from powders. It must be remembered that metal powders present very considerable frictional resistance in a pressing die, and will not flow to anything like the same extent as do most plastic materials. This is a fundamental matter and must always be borne in mind. It prevents, for example, the manufacture of pressings having extremely thin sections in the direction of pressing, or of pressings having re-entrant angles. There is also, at the present time, a very definite size limitation if the parts are to be produced in large numbers from comparatively inexpensive equipment. There is, however, no real upper limit to size, provided sufficiently large presses are available. Powder metallurgy has one limitation in common with processes of the die-casting type, and this is that a sufficiently large number of any one part must be required to offset the costs of the die and plant.

Template Manufacture. (*Aircraft Production, January, 1942, Vol. IV, No. 39, p. 164, 4 figs.*)

Lofting as an aid to production; new duplicating process developed by Westland Aircraft. Laying out a master template on the floor of the mould loft. A roller is used to ink the master template in readiness for duplicating. For duplicating, the inked master and the copy template are placed between rubber-faced steel platens on a power-operated screw-

press. Shaping the template on a filing machine. To obtain the greatest possible accuracy, the girl operator views the contour lines through a magnifying lens.

Taper Gauge and Butted Tubes. (*Aircraft Production, January, 1942, Vol. IV, No. 39, p. 147, 1 fig.*)

Advantages, including reductions in weight and machining costs, are claimed for the emloyment of taper gauge tubes in aircraft constructions. Examples of tubes which have been produced and their possible application. Sections of taper gauge tubes produced for the Blackburn Botha, showing the manner in which the wall thickness can be varied and parallel sections included.

Cherry Self-plugging Rivet (Incorporating Mandrel) for Blind Riveting. (*American Aviation, U.S.A., Vol. 5, No. 12, 15/11/41, p. 47.*)

The self-plugging Cherry rivet has a mandrel with an expanding section and a head on the blind side. In installation the assembly is inserted into the rivet hole until the head of the hollow rivet takes its ordinary position relative to the material being joined. Through the use of the combination hydraulic and pneumatic gun the expanded section on the blind side is pulled into the hollow body of the rivet, expands the shank, and forms a tulip head in the back. The outside end breaks off during application and can be trimmed off with ordinary nippers. Aircraft factory tests are said to have indicated that one man (unskilled) can install and trim 540 Cherry rivets per hour.

The outstanding feature claimed for the part is its positive mechanical action. The force required to apply the rivet breaks the mandrel and accomplishes two results: it creates a clinching action, holding the two sheets together securely, and also it expands the rivet, causing the necessary pressure fit of the shank.

(*Communicated by D.S.R., Ministry of Aircraft Production.*)

MATERIALS, MATERIAL TESTING.

Alloy Cast Irons, by J. G. McGrath. (*The Machinist, December 13, 1941, Vol. 85, No. 38, p. 849, 3 figs.*)

The discussion of cast metals concludes with comments on the hardening of Meehanite, and malleable and grey cast irons.

One Good Way to Save Aluminium (Die Casting instead of Sand Casting), by H. Chase. (*Metals and Alloys, August, 1941, Vol. 14, No. 2, p. 152.*)

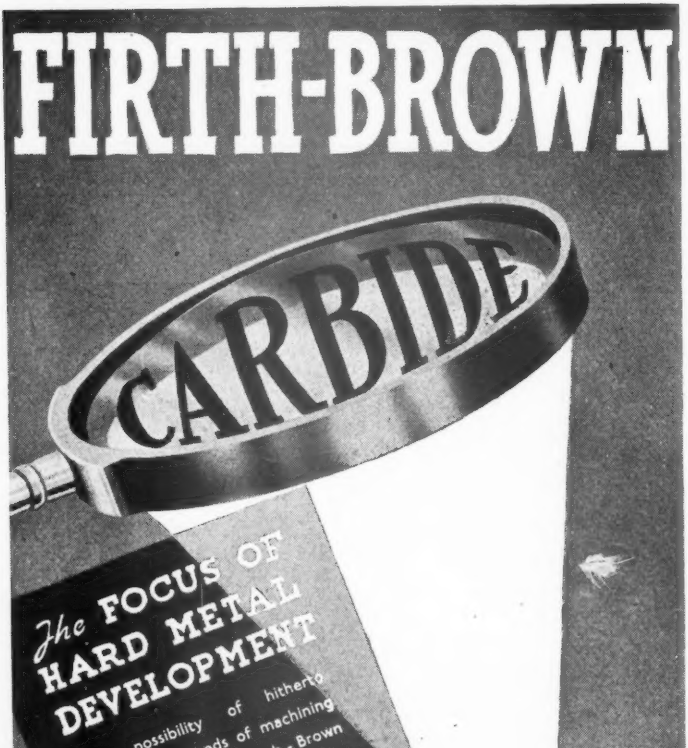
A letter suggesting that material and labour could be saved by the substitution of gravity die-casting for sand casting. Brief notes on technique.

(*Communicated by the British Non-Ferrous Metals Research Association*)

Corrosion Studies of Magnesium and its Alloys, by J. D. Hanawalt, C. E. Nelson, and J. A. Peloubet. (*Metals Tech., September, 1941, Vol. 8, No. 6 A.I.M.E. Tech. Pub. 1353.*)

A detailed study of corrosion as a function of alloy composition, including tests of the specific effect of Al, Mn, Zn, Fe, Ni, Cu, Si, and Pb singly and in combination. Alternate immersion tests in 3% NaCl; solution potential and hydrogen over-voltage measurements; examination of corroded surfaces by electron diffraction.

(*Communicated by the British Non-Ferrous Metals Research Association*)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Classification of Copper and Copper Alloys, by H. J. Miller. (*Metallurgia, October, 1941, Vol. 24, No. 144, p. 178, November, 1941, Vol. 25, No. 145, p. 16.*)

Tabulated data on the more important Cu-base materials, giving British specification numbers, compositions, mechanical properties (tensile and hardness), &c. Wrought forms of Cu; castings; conductivity alloys; commercial brasses and Mn bronzes in the form of cold-rolled strip and sheet, hot-rolled plate, wire, tubes, rods and sections, and castings; cast phosphor bronzes and gunmetals; Al bronzes; Cu-Pb bearings; wrought phosphor bronzes.

(*Communicated by the British Non-Ferrous Metals Research Association*)

Weldable Alloy Materials, by T. B. Jefferson. (*Welding Eng., October, 1941, Vol. 26, No. 10, p. 57.*)

A list of 317 alloys, ferrous and non-ferrous, tabulating their compositions, chief mechanical properties, and available forms, together with their weldability by arc, gas, and resistance processes.

(*Communicated by the British Non-Ferrous Metals Research Association*)

Thermostat Metal (Bimetal), by S. R. Hood. (*A.S.T.M. Standards on Electrical Heating and Resistance Alloys, September, 1941, p. 93, B.N.F. Serial 24, 188.*)

A general paper (with no detailed reference to specific metals) on the theory, design, &c., of bimetals.

(*Communicated by the British Non-Ferrous Metals Research Association*)

Magnetic Powder-Etching for Crack Detection. (*I. and Coal T. Rev., 25/7/41, p. 73.*)

Particulars are given of methods used in Germany for the magnetic testing of metallurgical objects. The article is abstracted from a report published in "Stahl und Eisen." Apparatus for the test, using an oil film with iron filings in suspension, and apparatus for the magnetic impulse type of testing have been developed. Considerable attention is paid to the interpretation of diagrams, magnetising conditions, and to the effect of direction of magnetisation. It is finally concluded that magnetic etching or spraying should be supported by additional metallographic investigation to verify the presence of flaws and cracks.

(*Communicated by Research Dept., Met.-Vick.*)

Investigation on the Suitability of Certain Heat-resisting Materials for Employment in Internal Combustion Engine—IV. (H. Cornelius and W. Bungardt. *L.F.F., Germany, Vol. 18, No. 9, 20/9/41, p. 305. R.T.P. Translation No. 379.*)

Previous tests carried out by the D.V.L. had shown that the most suitable material for the blade of exhaust driven turbines consisted of an austerritic alloy of Ni, Co, Cr, W, and Mo, with about 2% of Ti and relatively little iron ($\triangleq$13%). The present report deals with the effect of increasing the iron content at its expense of Ni, Cr, or Mo. Twelve alloys were investigated in all, including two austerritic types of the old composition for comparison. Creep tests were carried out over the temperature range 600°—800° for periods up to 300 hours, with determination of the following factors:—

D_1=stress in $K_{g/mm2}$ corresponding to a creep rate of $10 \times 10\%/^{h}$ between 25th and 30th hours of loading (so called DVM short period test).

D_2=stress producing a creep rate of $5 \times 10\%/_{h}$ between 100th and 300th hour of loading (1% extension after 2,000 hours if creep rate remains constant).

1/300=stress producing a total extension of 1% after 300 hours.


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In addition the average creep rate between 100th and 300th hour under a stress γ_{D_1} was recorded. The results show that no definite relationship between the various creep strength can be established, and that the DVM short period test is not sufficient to establish the behaviour of the material when subjected to high temperature stressing over a long period.

As already pointed out in the previous papers, in addition to creep strength, both the density as well as the resistance to scaling at high temperatures determine the suitability of turbine blade materials. When viewed from all these aspects, the alloys investigated in the present report are found to be less suitable than the original austerritic parent alloys of lower iron content.

(Communicated by D.S.R., Ministry of Aircraft Production.)

Effect of Roughness of Cast-iron Brake Drums in Wear Tests of Brake Linings. (W. A. Taylor and W. L. Holt. *J. Nat. Bur., Stands, U.S.A., Vol. 27, No. 4, October, 1941, p. 395.)*

Five representative types of commercial brake linings were tested against centrifused cast-iron brake drums having widely different values of roughness. It was found that (1) the rate of wear of brake lining is an increasing function of the initial roughness of the drum; (2) the actual wear characteristics of a given lining are a function of the character of the surface of the drum, and of the type and quality of the lining; (3) the roughness of the drums, in general, has a greater effect on the wear of woven linings than on the wear of moulded linings; and (4) the rate of wear of brake linings tested against relatively smooth drums becomes practically constant after the first few hundred stops. For relative wear tests a drum of specified type and finish having a roughness of not more than 15 microinches (root mean square) is recommended.

The effect of the roughness of brake drums in service is probably similar to that obtained on the testing machine, but less in magnitude.

The coefficient of friction appears to be slightly lower the rougher the drum, but for all practical purposes the effect of roughness on the coefficient of friction may be neglected.

(Communicated by D.S.R., Ministry of Aircraft Production.)

MEASURING METHODS, APPARATUS.

On the Level, by E. R. Gregg. (*Machine Shop Magazine, December, 1941, Vol. 2, No. 12, p. 69, 14 figs.*)

The uses to which spirit levels of the better classes may be put are innumerable. The British Standards Institution has recently issued a specification, No. 958/1941, on "precision levels." Level vials. Ordinary mechanic's levels. Precision levels: (a) block level with continuous base, (b) block level with interrupted base, (c) frame or box level. Building machine tools. Setting-up on machine tools. Measuring machines. Circular level used on jig borer: (a) to line up the circular table and machine spindle, (b) to set the spindle definitely to a tilted circular table. Measuring length gauges. Measuring angles.

Non-destructive Testing. (*Automobile Engineer, December, 1941, Vol. XXXI, No. 418, p. 448, 6 figs.*)

The need for rapid examination of parts without damaging them has led to the employment of ray technique. Details are given regarding equipment in current use and in process of development, with a consideration of the use of the stethoscope in making acoustical tests.

MECHANICS, MATHEMATICS.

Plastic Theory: Its Application to Design, by Prof. J. F. Baker and J. W. Roderick. (*The Welding Industry, December, 1941, Vol. IX, No. 11, p. 275.*)

It had become obvious that in all welded connections one was, in fact, dealing with plastic material, and that no welded structure would stand up to its work unless the material were behaving plastically. Use of small models. Future bridge design. Stress diagram for a beam. In making full use of plasticity and the plastic range one was distributing bending moments in such a way as to arrive at lower stresses than were supposed to occur according to our limited knowledge. The intelligence of the material. Limit of proportionality. Upper and lower yield stresses. Knife-edge loading.

POWER, DRIVE.

Machine Tool Motor Selection. (*The Machinist, December 13, 1941, Vol. 85, No. 38, p. 292E.*)

The application of electric motors to machine tools is considered under the following heads: (1) supply details; (2) type of enclosure: this depends almost entirely on the location; (3) mounting: a very large percentage of motors are of the standard horizontal spindle, foot-mounted type; (4) bearings and vibration: the industrial alternating-current motor provided with three ball and roller bearings is normally fitted to the majority of machine tools where an exceptionally high degree of finish on the work is not required, or where the situation or method of mounting the motor prevents its slight vibration affecting the work or tools; (5) starting torque; (6) speed control; (7) duty cycles and reversing motors: the determination of the rating required for a given machine tool is dependent on a number of factors, one of the most important being the duty cycle. No definite rules can be laid down for the h.p. required by machine tools, and each case should be considered individually to ensure that the right motor is selected. The type of material being machined, the type and condition of the cutting tools and the cutting speeds and feeds employed give such a wide variation in power demand that it is impossible to offer an approximate figure for a given machine. This is illustrated by the fact that on two similar machines, set-up for different work, the correct motor powers were 4 h.p. and 12 h.p. respectively.

The Physics of a Transmission Line, by Professor W. M. Thornton. (*Journal of the Institution of Electrical Engineers, Part II, December, 1941, Vol. 88, No. 6, p. 561.*)

The electrical transmission of energy by systems of conductors is an engineering problem with four factors: economic, mechanical, electrotechnical, and physical. The first three are the constant consideration of those responsible for the design, construction, and operation of transmission lines; the last, though in itself of no less importance for the complete understanding of the process by which energy flows, is more a matter of principles than of practice. The purpose of a transmission line: transfer of potential energy by strain of the insulation. Properties of the ether: Maxwell's theory. Flow of electromagnetic energy: Poynting's theorem. An electric field between charges and its transfer to kinetic energy. The physical nature of resistance. Inductance and the energy of a magnetic field. Capacitance and electrostatic energy. Transmission along cables. The reaction between electric and magnetic fields. Single-phase and three-phase transmission. The function of insulation. The nature of corona. Moisture films on insulators. Mechanical design of insulators.

PSYCHOLOGICAL INVESTIGATION.

Measurement of Mechanical Aptitude, by R. Schultz. (*The Machinist, December 13, 1941, Vol. 85, No. 38, p. 845, 5 figs.*)

Employers look for men who learn quickly, have a capacity to do the work required. Many concerns have used aptitude tests to select their personnel. The present shortage of labour may be eased by giving some consideration to the following procedures: (1) Select and assign men to do specific jobs at the maximum level of their ability and experience. (2) Do not limit the search for machinists and mechanics to only those who claim interest or have had experience in this field. Aptitude tests have shown that a great supply of men suitable for training in machine and mechanical work may be found among such occupational groups as office workers, truck drivers, salesmen, gas station attendants. As a means of weeding out the untrainables, aptitude tests have worked out just about 85%. It is not necessary to talk at length to a man with varied experience in order to find out whether he is able to handle a certain job. Instead, merely give him a form consisting of 20 questions, as illustrated for lathe work in Chart IV. This method quickly separates men as follows: bluffers, those with limited experience, semi-skilled, and skilled workers. The immediate values in using more precise selection methods may be listed as follows: (1) An audit is made of the abilities of the labour supply as it is available. (2) A simple and practical classification is set up for all employees. (3) A useful inventory of needs for training of men is automatically prepared for the company. (4) It is a basis upon which men can be assigned immediately to production as specialists, and may be further trained for up-grading or more difficult work on jobs requiring a higher degree of skill. (5) Just as good production methods demand a continuous physical inventory of manufacturing and control, so an inventory on man power provides the key for insuring and controlling production schedules.

What is Wrong with Personnel Management? by Charles A. Drake. (*Personnel, U.S.A., November, 1941, Vol. 18, No. 3, p. 121.*)

Too many personnel men lack a professional attitude towards their work. In interviewing 29 selected candidates for personnel-manager positions Drake found nearly all of them entirely unfamiliar with modern scientific practices; in fact, many of them combined a complete ignorance of the techniques of the interview with an almost mystical belief in their ability to select employees by the interview alone. His article outlines procedures which educators and executives must follow if this situation is to be rectified.

SHOP AND SHOP MANAGEMENT.

Some Important Factors in the Maintenance of Electric Motors. (*Machinery, December 18, 1941, Vol. 59, No. 1523, p. 325, 2 figs.*)

Modern maintenance of electric motors involves periodic and systematic inspection by trained and competent men. When efficiently conducted, such inspection can be made the basis for considerable savings. All points at which trouble is likely to occur must be checked and new ones constantly sought out, careful records must be maintained, and a regular inspection schedule must be faithfully adhered to. The following suggestions, which are based on average conditions in so far as duty and dirt are concerned, may be helpful: once a week check oil level, free movement of oil-rings and temperature. Once a month check brushes, brush-holders, and shunts, and blow out motor with air. Once a year check air gap with a feeler gauge; check insulation resistance with megger; check line voltage with voltmeter; check load with

ammeter; and check renewal parts stock in the light of the past year's experience. Every two years dismantle, clean, and varnish windings; see that all windings are tight; and replace loose wedges and bands. Rationalised maintenance means more than repairing breakdowns. The article deals in detail with maintenance of lubrication, inspection of bearings, testing, cleaning, and drying insulation, checking current collecting devices.

A Time and Motion Study Man Looks at Personnel Administration, by P. Carrol, jun. (*Personnel, U.S.A., November, 1941, Vol. 18, No. 3, p. 165.*)

Personnel as a function. Need for better organisation. Operator selection and training. Follow-up of complaints. Wages and earnings. Foreman selection and education. Selection of time study men. Time study training.

SMALL TOOLS.

Adjustment and Measurement of Tool Tips—I, by Paul Grodzinski. (*The Machinist, December 6, 1941, Vol. 85, No. 37, p. 284E, 7 figs.*)

Experience has led to recognition of the fact that it is absolutely necessary not only to apply high speeds and fine feeds, but also to keep the cutting angles and the cutting conditions close to the values found best during investigations or by trial. Measurement of angles on radii on tool edges may be considered the basic problem. The Simon measuring device for the angles of turning tools enables the perfect measurement of the cutting edge of a tool with reference to the supporting face of the tool shank. Another instrument based on similar principles can be applied to tools adjusted in the machine; further, the height can be measured of the cutting edge above the tool base. Of advantage in the production and reconditioning of tool edges are fixed grinding gauges, which check the tool angle for various values, the side faces of the gauge controlling the rake angle, if both tool and gauge are adjusted on a common level base. Usually fixed gauges can check a radius between certain limits only; for accurate tool edges optical means are recommended, and in many instances also check the surface finish of the tool edge. For the production and reconditioning of tool angles the grinding machines must have adjustable tool rests. Modern tool grinding and lapping machines are provided with this quadrant adjustment, usually in one direction, whereas for tool edges with back rake angle, adjustment in two mutually perpendicular planes is necessary. The measuring of the tool edge solves only part of the problem, and until the adjustment of the tool in the machine is carried out with the same care no full use can be derived from careful grinding. A satisfactory height-adjusting device. The same device can be utilised for the adjustment of "hanging" tools and other purposes.

Diamonds and other Gem Stones for Instrument and Measuring Appliances. (*Engineering, December 26, 1941, Vol. 152, No. 3963, p. 518, 10 figs.*)

This article refers to the use of gem stones as bearings and pivots, wear-resisting plates, gramophone cutting and playing needles; also in hardness testing, surface roughness testers, and in optical instruments.

Diamond-impregnated Abrasive Wheels and Cutting-off Discs. (*Mechanical World, December 19, 1941, Vol. CX, No. 2868, p. 447, 2 figs.*)

The problem of satisfactory dressing the extra hard metallic carbide cutting tools has led to an increasing use of diamond impregnated


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grinding wheels. The selection and size of the diamond grains will be reflected in the finish produced and also in the quantity of metal removed. The practice of frequently burnishing tools by hand polishing prolongs the life of the carbide tip, with considerable economic advantage.

SURFACE TREATMENT.

The Purification of Plating Solutions, by O. A. Stocker. (*Met. Finishing, September, 1941, Vol. 39, No. 9, p. 479. Paper presented at Annual Convention, Amer. Electroplaters' Soc., 1941.*)

Impurities can be detected before serious trouble begins by the bent cathode test or the Hull cell test, and should be removed every few weeks. Efficient methods are outlined for purifying Ni, acid and cyanide Cu, brass, Cd, cyanide and acid Zn, and Ag solutions.
(*Communicated by the British Non-Ferrous Metals Research Association*)

TECHNICAL EDUCATION.

A Criticism of Teaching in Industry, by E. C. Maxcy. (*Personnel, U.S.A., November, 1941, Vol. 18, No. 8, p. 125.*)

To train skilled workers for defence production in the most effective manner, industry must avail itself of the latest developments in the educational field. The adult-education movement has resulted in the discovery of adult-learning characteristics, and hence of new techniques of teaching. These new techniques must be utilised if maximum benefits are to be obtained from industry's training programmes. Some criticisms of present training methods. Ways in which industry may make use of the new knowledge.

WELDING, BRAZING, SOLDERING.

The Welding of Monel, Nickel, and Inconel by the Arc and Resistance Processes. (*The Welding Industry, December, 1941, Vol. IX, No. 11, p. 259 2 figs.*)

Electric welding practice with monel, nickel, and inconel resembles that applicable to steel. Warping and buckling will be the same. Nickel and inconel can be welded in any position, but with these metals it is preferable to position the work for downhand or flat welding. Electrodes. Polarity. Welding currents. Surface preparation. Preheating. Electrode position and manipulation. Current for metallic arc welding of monel, nickel, and inconel. Test results on monel, nickel, and inconel sheet. Heat effect of welding. Welding dissimilar metals. Carbon-arc welding. Spot and seam welding. Flash welding. Strength of welded joints. Test results on butt joints—nickel to steel. Beryllium copper alloy for bronze and brass. Arc welding of copper, bronze resistance welding.

Arc-welded Gun Carriages. (*The Machinist, December 27, 1941, Vol. 85, No. 40, p. 921, 18 figs.*)

The 37mm. A.A. carriage consists of eight major weldments. All major weldments are first set up in a jig and tack welded. Wooden templets edged with strip aluminium are used to guide the cutting torches. All joints are arc welded. In all welding operations complete instructions are given as to the direction and sequence of welds. Coated electrodes are used exclusively. The chassis weldment is then stress annealed and sand blasted.

Oxy-acetylene Gouging — A Frame-machining Process. (*Machinery, December 4, 1941, Vol. 59, No. 1521, p. 268, 4 figs.*)

Oxy-acetylene gouging is a rapid and economical method of producing a U-shaped groove in the surface metal of rolled, drawn, forged, or cast

steel. The gouging process depends basically upon the design of a special nozzle to deliver a relatively large volume of oxygen at low-jet velocity. This jet, coupled with proper pre-heated flame distribution, and guided by a simple gouging manipulation, will cut a smooth, accurately-defined groove in the surface of steel plate. By using different nozzles and manipulation the groove can be varied in width and depth at the will of the operator. In general, gouging applications can be classified in four groups. These consist of the following: (1) progressive gouging of the under-side of electric arc welds; (2) spot-gouging in the removal of defective weld metal and temporary tack-welds; (3) plate-edge preparation for welding; and (4) maintenance and scrapping operations.

Spot-welding Jigs for Aircraft Work. (*Machinery, December 11, 1941, Vol. 59, No. 1522, p. 293, 6 figs.*)

Present production schedules in aircraft building have enabled methods to be adopted which would not have been economical under smaller schedules of manufacture. In the welding department of the Douglas Aircraft Co. jigs have been adopted for most of the spot-welding operations with a subsequent reduction in welding time ranging up to 50 per cent. Most of the time saved has resulted from eliminating the need for laying out work prior to welding, the parts to be welded together being properly located in the jigs with respect to each other. Also of prime importance is the fact that the use of these welding jigs provides complete interchangeability of the welded products. Some of the typical jig designs used are described in this article.

Machine Design. (*The Stabilizer, U.S.A., Vol. 10, No. 3, p. 22, 9 figs.*)

Press to be changed over to welded construction one part at a time. Illustrations: Eye (cast construction), Clevis (cast construction). Using a tapped tube for the arm which is welded to a larger piece of tubing serving as the bearing. Design made from two squares (both the same size) connected by a strap. The strap is then welded to both parts. Still another method would be to use two square bars and a strap. Still another construction would be to use a square and a flat bar section. The use of a tube and strap or bar. This design makes possible a cost reduction of about 46% and a weight reduction of about 56%. Final design is using two straps welded to a bar.

WORKS AND PLANT.

War-time Factory Building in Britain. (*The Australasian Engineer, October 7, 1941, Vol. 41, No. 305, p. 17, 4 figs.*)

The design of factories during war-time introduces many problems that are of no account in days of peace. During the first two years of war special study has been given to these problems of British architects and engineers. A special War-time Building Bulletin containing recommendations is reviewed.

Black-out Installation for Factory Roof-lights. (*The Commonwealth Engineer, October 1, 1941, Vol. 29, No. 3, p. 68, 1 fig.*)

Not the least problem for factory management is the "blacking out" of roof-lights in a reasonably simple and effective manner, yet at the same time allowing their use during the daylight hours. An arrangement is shown which provides for "blacking out" 550,000 sq. ft. of roof lights in 15 seconds by pressing a button, and doing the reverse process in the same way and in the same time. Method of fixing movable shutters over roof-lights.

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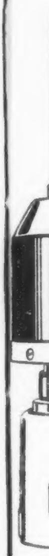

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